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FLIGHT

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Editor-in-Chief
MAURICE A. SMITH D.F.C.

Editor
H. F. KING M.B.E.

Technical Editor
W. T. GUNSTON

Production Editor
ROY CASEY

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Wanted: A Fourpenny Freighter

MANY years ago an American politician declared that what America really needed was a good five-cent cigar; and just the other day another such opined, with the same homespun sagacity, that his nation's need was a good five-cent air freighter. He meant an aeroplane that would carry freight at a direct operating cost of five cents (say fourpence) a ton-mile. The five-cent cigar is today a household metaphor, and the five-cent freighter may well achieve a similar distinction. Certainly there is far more in the idea than political smart talk; because air freighting is going to be very big business indeed.

If any aircraft builder is competent to predict just how big that business will become it is surely Douglas: and when Donald W. Douglas, Jr., the company's vice-president, goes on record as saying that by 1970 air freight tonnage will exceed total passenger-load, we in Great Britain will do well to pay heed.

Already the portents are plain. Recent days, even, have seen a phenomenal up-cropping of proposals for big freighters, notably swing-tail versions of the Canadair CL-44, Convair 600, Douglas DC-8 and Boeing 707. In the medium field we ourselves seem to be off to a head start with the A.W. Argosy; and the Short Britannic has been ordered for the R.A.F. largely on the grounds of its "exceptional economy" (we quote the Minister of Supply) in civil and military freight operations.

So far, so good. But if ever we should fail in this business of building and selling big, economical freighters, we may have to put up the shutters over another large section of our national shop-frontage.

Short-range Decision

IT is in no sour-grapes sense that we refer once again to the decision of I.C.A.O.'s special meeting on short-range navigation aids. The controversy that raged so hotly at Montreal will not be quickly forgotten if the recommended aid proves inadequate to its task of providing separations in the crowded air.

The aftermath of Montreal is not bitterness that Decca was examined and found wanting, but the feeling that it was not really examined at all. Under the agenda of the meeting, one committee was to determine the problems of a short-range aid and find general and then qualitative and quantitive solutions; a second committee was to list the capabilities of existing and proposed aids—in practice Decca and VOR/DMET—and review them in the light of the work of the first.

The agenda was never completed. After some wrangling, a list of problems and qualitative requirements was drawn up, but on four points the U.K. and U.S. delegations could not agree. On each score, Decca claims superiority to VOR/DMET. The rival aids were not reviewed against the operational requirements. It was taken that there had been ample opportunity for delegates to become familiar with the subject without further detailed consideration. Decca was withdrawn in protest; a vote was taken, and a new aid came one step nearer adoption as an international standard.

The Montreal conference could never reach agreement while the chief delegations adhered to implacable points of view. But important as the cohesion of I.C.A.O. may be, the M.T.C.A. team took the only possible course in refusing to compromise the pilots, operators and controllers of a few years hence by submitting under pressure to what they believed to be a faulty technical decision.

VÆ VICTIS!: These Victor B.1s in final assembly at the Handley Page factory at Radlett were inspected by the Minister of Supply last Friday. The event and the aircraft are described on this and other pages

FROM ALL QUARTERS

Black Knight No. 2

LIKE its predecessor, the second Black Knight ballistic rocket test vehicle was a complete success when it was fired at Woomera before dawn on March 12. Described in our issue of October 17, 1958, Black Knight was designed by the R.A.E. in partnership with Saunders-Roe, and Bristol Siddeley make the four-barrel rocket engine to a basic design by the R.P.E. Firings are taking place at Woomera in collaboration with the W.R.E. and the vehicles are tracked throughout their mission and recovered. New safety techniques have been developed for these trials, and very comprehensive instrumentation has been fitted to both the rounds so far fired. Last week's test was one of a number planned to obtain "further scientific information," and the peak of its trajectory was at an altitude of some 350 miles.

News about Engines

THIS issue is *Flight*'s fourth review of the world's aero engines. Included in the 25-page descriptive section are a number of items which are of particular news value. For the first time it is possible to publish authentic drawings of the de Havilland Gnome P.1000 fixed-wing turboprop and Rolls-Royce RB.141 by-pass engine, and provisional drawings are included of the Super Atar, the big Heinkel turbojet, J58, J85 and Solar Titan.

Marcel Dassault Honoured

AT the twelfth Louis Blériot Lecture on March 12 (see p. 380) the Gold Medal of the Royal Aeronautical Society was presented *in absenna* to M. Marcel Dassault by the president, Sir Arnold Hall. As M. Dassault was unable to attend personally, the medal was received on his behalf by his assistant, Gen. Pierre M. Gallois. The Gold Medal is the highest honour the Society can confer, given for work of distinction in aeronautics; and it goes to the well-known French designer for "his outstanding contributions to the design and development of aircraft."

Marcel Dassault, who was born in 1892, designed a wooden propeller during the First World War which was used on French combat aircraft (including the Spad flown by Guynemer). One of his first aircraft designs was the S.E.A. 4 (in 1918) and the latest is the Mirage IV (his Mirage I made its maiden flight in 1955). Between the wars he designed many successful types.

After France was invaded M. Dassault was in the Resistance; taken prisoner, he was sent to Buchenwald, being liberated in 1945. Since the war his company has produced the Ouragan and Mystère fighters in addition to the Mirage series. The Mystère has been adopted by the French, Indian and Israeli Air Forces; and the Mirage III reached Mach 2 recently with its Nord 5103 missile in place.

Victor Production on View

THE Minister of Supply, Mr. Aubrey Jones, visited the Handley Page factories at Radlett last Friday to inspect production of Victor B.1s for the R.A.F. and to watch a flight demonstration of the first Victor B.2. Flown by J. W. Allam, this machine took off in a mere 410 yd using 100 per cent thrust from two of its Rolls-Royce Conways and reduced thrust from the remaining two.

Addressing an invited audience before the flight, the Minister said that the Victor B.1 was already a favourite in Bomber Command and that the pilots were regularly getting from the aircraft "more than they should be doing." (Rumour has it that the "more" referred particularly to high speeds.) The Victor B.2, he continued, would remain one of the mainstays of Bomber Command for ten years. He referred also to the company's other projects, the private-venture Herald and boundary layer-control work, certain difficulties in which had recently been overcome. Mr. Jones went on to say that he had just received, and was about to study, the report of the industry committee on the economics of the supersonic transport. He was also able to announce that an R.Ae.S. Gold Medal had just been conferred on Mr. R. S. Stafford, the company's technical director.

Visitors to the Radlett and Cricklewood plants learned of the remarkable characteristics of the sandwich construction technique, some aspects of which are described on pp. 372-373.

Mr. S. Scott-Hall for Australia

AT present Scientific Adviser to the Air Ministry, Mr. Stewart Scott-Hall has been appointed Head of the United Kingdom M.o.S. staff in Australia. He succeeds Dr. W. H. Wheeler, who is returning to this country to take up an appointment as Director of the Ministry's Explosives Research and Development Establishment at Waltham Abbey. Mr. Scott-Hall has been at Air Ministry since October 1956.

The Reliable Viper

IN order to demonstrate the very high standard of reliability of the Bristol Siddeley Viper 8 turbojet on the eve of its entry into service with R.A.F. Flying Training Command, a standard production engine was recently subjected to a particularly arduous 500 hr programme of intensive flying in a Hunting Jet Provost. The test started on September 30 last and was completed on March 4. No less than 22 per cent (111 hr) of the 500 were flown at take-off r.p.m., in order to simulate training duties in which an exceptional proportion of the time is at high power settings.

The original schedule specified eight one-hour sorties daily, with 30 min allowed for refuelling. In the event the turn-round time was considerably reduced, and on one day nine flights were

FIRST STEP into space by a pilot: on March 10 the first North American X-15 made a 69-min flight from Edwards A.F.B. attached to the B-52A mother ship throughout. Scott Crossfield was in the cockpit

completed at an average interval between missions of 12 min. The overall utilization was 5 hr 45 min per day, notwithstanding the fact that 23 days were completely ruled out by bad weather. The pilots were T. P. Frost (chief test pilot), A. H. Wittridge, H. W. Rayner, J. Pollitt and M. Morss, all from Bristol Siddeley, and Geoff. Worrall and J. G. Towle from Gloster Aircraft.

P.531s for the Navy

A PRE-PRODUCTION contract for Saunders-Roe P.531 helicopters was last week placed by the Ministry of Supply on behalf of the Royal Navy. This is the first order received for the P.531, which was developed by the company as a private venture. It flew in 6½ months from the start of the design proper, and made its public debut last September at the S.B.A.C. Show at Farnborough. The aircraft is a five-seater general purpose helicopter powered by a Blackburn Turmo 600. The first deliveries of the M.o.S. order will probably be made early next year.

The Sixth Barnwell Lecture

ON March 11 the sixth Barnwell Memorial Lecture was held by the Bristol Branch of the Royal Aeronautical Society. The paper was read by Mr. Cyril F. Uwins, O.B.E., A.F.C., F.R.Ae.S., for many years Bristol's chief test pilot and now deputy chairman. In it he traces his own record of 54 prototypes and over 120 different basic aircraft in his log-book. We expect to make further reference to the occasion next week.

Philip Wills Steps Down

THE news that Philip Wills and Geoffrey Stephenson have retired from world championship gliding was contained in a committee report presented at the annual general meeting of the British Gliding Association last Saturday. They have decided to make way for younger pilots in the British team for the next international contest, which will be held in 1960.

In his annual report to the meeting as B.G.A. chairman—a post he has held for the last twelve years—Mr. Wills said that the association's problems, including the most important one of security of tenure at gliding sites, stemmed primarily from the absence of a government policy on any aspect of sporting flying. During the year, security of tenure had been obtained at Perranporth and at a new site at Tebay Ghyll in Westmorland; but the Halifax, Perkins and Kent clubs were facing destruction and the Midlands club at the Long Mynd had been blanketed by a new Aircraft Advisory Route. Negotiations towards security at Lasham were proceeding slowly but hopefully; Coventry and Newcastle were still in doubt.

Statistics for 1958 included totals of 21,536 hours flown from 135,074 launches (increases of 1,192 hr and 15,050 launches over the totals for the previous year). The most striking membership increase was that of private and group owners, who numbered 71 compared with 51 a year ago.

Criticism of the international gliding research organization OSTIV was also included in the chairman's report, which pointed out the anomaly of a scientific and technical body controlled by representatives of national aero clubs (which were neither scientific nor technical). The current OSTIV task of producing a set of international design requirements was considered by the B.G.A. to be "altogether too big a task for such a scattered organization."

Manston for Civil Use

REFRESHINGLY in these days of lost airports comes the news that Manston is soon to be available for civil use. Well sited meteorologically, this Kentish airfield has been in Service use since it was constructed for the R.N.A.S. in 1916, but for some nine years from April 1946 it had Customs facilities and was available for civil diversions. Then the U.S.A.F. moved in, and they have only recently left. The airfield remains Air Ministry property, and the control tower will be manned by the R.A.F.

The first civil operators will be Silver City Airways, who on June 15 will use Manston as a base for a new rail-air-rail service from London to Paris, to be known as "The Silver Arrow" and flown with 68-seat H.P. Hermes; this will be the first use of these aircraft on cross-Channel services. The starting date of the new service coincides with completion by British Railways of electrification of the line which forms the U.K. rail link. Margate is the probable rail terminal, and passengers will be conducted from there to Manston by bus. The French rail sector will be operated by diesel cars from Le Touquet to the Gare du Nord, Paris. Silver City are investigating the economics in collaboration with the British and French railways, and they hope that the outcome will be the construction of rail spurs into each airport.

Initially the Silver Arrow service will leave London at 0940 hr and arrive seven hours later, but if rail terminals are constructed at each airport (as at Gatwick) the overall journey should be little more than an hour longer than the present centre-to-centre time via London Airport and Le Bourget. Return fare is to be £8 19s. The Silver Arrow will eventually be a year-round service.

QUESTION TIME: During his recent visit to Northern Ireland Mr. Macmillan visited the works of Short Bros. & Harland Ltd. Here he is seen inspecting a landscape model illustrating VTOL fighter possibilities. With the Prime Minister, l. to r., are Mr. H. G. Conway, joint deputy managing director and chief engineer; Mr. F. H. Robertson, chief project designer; and Sir Matthew Slattery, chairman and managing director

Silver City's use of Manston is understood to be on a rental basis and without the guarantee of indefinite tenure; but Mr. Eoin C. Mekie, the company's chairman, has expressed confidence that their tenancy will be a long one.

The new venture reflects the enterprise of Silver City, whose own airport at Ferryfield is said to be operating at "near to capacity" at the peak season. It is intended eventually to take advantage of road developments (including the Thames tunnel at Tilbury) to introduce a vehicle ferry service from Manston; the company's licences to Ostend, Calais and Le Touquet are interchangeable in this respect. Although some building construction will have to be done before passengers can be adequately handled, Manston is well equipped in other ways; the runway is 9,200ft long and 750ft wide, and FIDO is installed.

IN BRIEF

Flown by S/L. Eric Franklin, the second production A.W.A. Argosy made its maiden flight, of 2hr 20min, last Saturday.

* * *

Lt-Cdr. J. S. Overbury, formerly of Saunders-Roe Ltd., has been appointed a member of the Hunting Aircraft test-pilot team. He has flown 2,600 hours on 70 types and holds two point-to-point speed records.

* * *

Orders worth more than $1m (about £357,000) for an advanced type of airborne radar for use in R.C.A.F. anti-submarine aircraft have been secured by E.M.I. Electronics Ltd.

* * *

A contract was signed last week at the Leipzig Fair between the East German government and D. Napier & Son. Worth £100,000, it involves precision-cast turbine blading for aero engines; the engine-type is not revealed.

* * *

Mr. Neill G. Bennett, a director of the Graviner Manufacturing Co. Ltd. and chief engineer of its aircraft division, has been appointed joint managing director with Mr. A. Mathison, who is also chairman.

* * *

Since our "Forthcoming Events" list (p. 414) closed for press it is learned that the Helicopter Association regional lecture to be given by Mr. Raoul Hafner at Eastleigh on April 4 has had to be cancelled.

* * *

Flight regrets to learn of the death, on March 12, of Mr. A. E. ("Bill") Smither, contracts director of Bell Precision Engineering Co. Ltd., of Crawley. He joined the company in 1954, after a career in Government service with the Ministry of Aircraft Production and the M.o.S.

* * *

A gift of £150 has been received by the Tiger Club from the Society of British Aircraft Constructors with the object of helping to improve the standard of British aerobatic flying in the Lockheed Trophy and other international contests. The award follows a suggestion made to the S.B.A.C. by the Air League of the British Empire.

* * *

Following the amalgamation of four Napier departments into a single technical organization under Mr. A. J. Penn, thirteen new appointments were announced last weekend. They include those of Mr. R. H. Chamberlain as chief engineer and Mr. R. A. Gilbert as chief designer.

* * *

West Germany is to buy fifty Fiat G-91s and has also signed an agreement to build the aircraft under licence. It has also been reported in Bonn that West Germany would this week conclude an agreement with Lockheed for the delivery of ninety-six F-104 Starfighters. The agreement was said to cover also the licence-production of another 200 Starfighters.

The first Victor B.2, on the left of the picture, in company with the second prototype B.1

BEHIND THE VICTOR

Development and Production of Handley Page's V-Bomber

AS recorded on an earlier page of this issue, production of the Victor was inspected by guests of Handley Page Ltd. on March 13. Simultaneously a considerable amount of new information was released.

THE Victor story goes back to the autumn of 1945, when Mr. G. H. Lee, now Handley Page's deputy chief designer, went to Germany to investigate swept-wing technique. With his conclusions as a basis, the company submitted to the Air Ministry a study for a four-jet bomber with wings swept at 45 deg. Although tailless configurations had been contemplated, the aircraft had a small unconventional tail unit to trim out aerodynamic moments due to flap operation or c.p. change in a dive. Normal fore-and aft control was by elevons and tip-fins formed wing end-plates. "It is to the credit of the British Air Staff," Handley Page remark, "that, after examining this projected bomber and reports from field teams investigating German research during the 1939-45 war, a requirement was promptly formulated. This ultimately resulted in the V-bombers."

Issued on January 1, 1947, the specification called for a bomber of an all-round performance similar to that of H.P.'s project but capable of near-sonic speed. Mr. R. S. Stafford, technical director, set up a team to make an exhaustive aerodynamic study, and Mr. G. H. Lee was appointed to lead it. Mr. C. F. Joy, chief designer, led a project group concerned with more general design features. Its function was to advance the design to a stage where scheming was complete.

It appeared that the required wing characteristics were: fairly large aspect ratio (for long range and high cruising altitude); high sweepback, to permit reasonable thickness/chord ratio without detriment to high critical Mach number. A wing of this type, however, was liable to stall first at the tip, leading to instability. The "crescent" wing apparently offered the best compromise between the conflicting requirements of high performance and good low-speed qualities, and this was adopted. Its characteristics have frequently been discussed in *Flight*.

Another early decision was to use fully duplicated power controls, eliminating manual reversion in emergency. The company remark that this was justified, for there have been no serious control difficulties.

During 1947 Handley Page received a contract for a prototype, powered by four Metrovick F.9 turbojets (later Sapphire) of 7,500 lb thrust each. "Although this project differed in many ways from the present Victor," the makers state, "the same pronounced wing configuration was incorporated. Originally the H.P.80—as the Victor was then called—was only slightly heavier than the proposal of 1946. Fins and rudders were again mounted on the wing tips although this arrangement was soon discarded for a more conventional tail unit. In common with other aircraft constructors the company had no wind tunnel capable of testing models over the whole of the necessary Mach number range. High Mach number tunnel testing was undertaken at the Royal Aircraft Establishment. Handley Page's transonic tunnel—powered by two Rolls-Royce Nene turbojets—was completed at Radlett in July 1953. From that time the tunnel undertook all high-speed testing of later developments in Victor design."

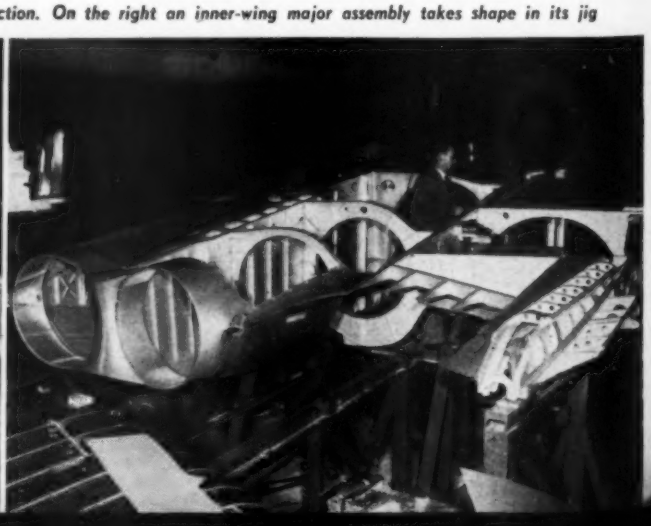
At the end of 1950 S/L. H. G. Hazelden, the company's chief test pilot, flew a Hastings with two Sapphires outboard. These delivered considerably more thrust than those specified earlier, and the Hastings flew comfortably at 170 kt on only one Sapphire —at normal cruising power. Its test flying, coupled with high-speed development with a Sapphire-engined Canberra, proved the Armstrong Siddeley turbojet ideal for the projected bomber.

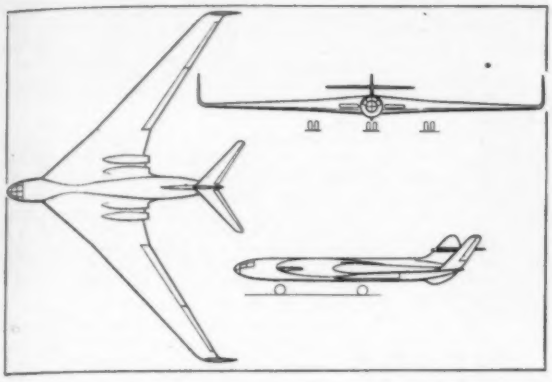
Originally it was intended to construct a gliding model for towing experiments, but this proposal was discarded when a decision was taken to build a flying replica. Small-scale crescent wings were designed to fit the fuselage of an Attacker, and construction and detail design of the aircraft (H.P.88) was entrusted to Blackburn and General Aircraft. It was hoped to get data which would be of help in designing the Victor. However, due to unavoidable delays, the H.P.88 did not fly until the middle of 1951, and by that time the Victor prototype was being built. Test flying of the H.P.88 was undertaken by F/L. D. J. Broomfield, who took the aircraft to Stansted for trials. Approaching for the first of several proposed runs at various speeds, the aircraft suffered a catastrophic structural failure caused by a control feature already discarded on the Victor.

Proving the Victor structurally required a vast programme of research combined with exhaustive testing. This was the responsibility of Mr. K. C. Pratt, then the company's development and test engineer.

Handley Page tell the story of the arrival of the first Victor fuselage at Boscombe Down in June 1952, and of subsequent vicissitudes. "For security reasons," they say, "all resemblance

On the left a Victor sub-assembly is under construction. On the right an inner-wing major assembly takes shape in its jig





The general-arrangement drawing on the left shows a 1946 project for an "unarmed high-speed bomber" for which "four J.P. engines" were specified. Span was 122ft. Above is a wind-tunnel model for a later scheme

BEHIND THE VICTOR . . .

between the fuselage and an aeroplane had to be avoided. A wooden structure built around it, suggesting the form of a large boat, masked the telltale shape. White sheets completed the disguise. Upon its side was painted the pseudonym 'Geleypandhy,' an anagram (whose deception was added to by a signwriter's error) of Handley Page. It was hoped to demonstrate the H.P.80 at that year's S.B.A.C. show at Farnborough. Another setback occurred, however, and, as in the case of the H.P.88, it had tragic results. A small fire broke out at the rear of the Victor's fuselage during a test of the hydraulic system. An electrician who received severe burns died sixteen days later. It took some weeks to repair the damage and it was not until a week before Christmas that the Victor began taxying tests. Bad weather delayed the first flight until Christmas Eve. At the controls was S/L. Hazelden, with Mr. I. K. Bennett as flight observer. . . . The Goons, in their weekly B.B.C. broadcast . . . gave their own version of the Victor story. The new bomber's eagerly-awaited first public appearance was at the Queen's Coronation Review of the R.A.F., when it flew in salute at R.A.F. Odiham."

Another setback came in July 1954 when the first prototype was lost at Cranfield. The first of a series of tests had been performed by S/L. Hazelden; later, when he was engaged at Handley Page's Woodley works, F/L. R. V. Ecclestone took over. On a low-level, high-speed run, the tailplane became detached following a fin failure. A second prototype (WB775) flew soon after the loss of the first and appeared at the Farnborough display that year.

Recent developments will be fresh in readers' minds. The first production aircraft flew on February 1, 1956, and production Victors were delivered for assessment to Boscombe Down during that year. In the spring of 1958 Victors became operational with No. 10 Squadron at Cottesmore; there No. 15 Squadron has been similarly equipped. At Gaydon No. 232 Operational Conversion Unit continues to train Victor crews, and a photographic-reconnaissance version of the Victor is in service at Wyton. The first Victor B.2—larger and much more powerful—has flown. Rocket-assisted take-off will increase its potential still further.

Victor production is concentrated in the Cricklewood and Colney Street factories, and Park Street (situated, as is Colney Street, at the Radlett airfield) is responsible for experimental flying, prototype building, testing and development. Although techniques do not call for a definite distinction between types of work undertaken at the factories, Cricklewood is primarily responsible for detail component manufacture (machined parts, stringers, etc.), sub-assemblies (wing panels, fuselage frames, etc.) and much major sub-assembly work (outer wings, air-brakes, control surfaces, etc.). Final-assembly production lines are at Colney Street, where a small quantity of detail components and major sub-assemblies are also manufactured.

When production was first envisaged it was decided to reduce to a minimum the number of complicated final-assembly jigs. This was achieved by the extensive use of relatively simple sub-assembly jigs; thus time spent in final assembly has been reduced. This structural breakdown readily lent itself to the manufacture of corrugated sandwich-skin panels, consisting of a corrugated core of aluminium alloy sheet attached to an inner skin by blind rivets and to an outer skin by spot welds. The result is a light structure of excellent stiffness and strength, wherein bending loads are carried by the skin. Conventional stiffening components have been considerably reduced in number. Corrugated panels enable fuel tanks to be pressurized without weight penalty and allow much space which would otherwise have been devoted to structure to be made available for these tanks and other equipment. Presses for corrugation manufacture and well-equipped spot welding and X-ray testing departments are at Cricklewood; corrugated sheet cores are produced on brake presses with a method of feed which ensures constant pitch and depth of corrugation. Sections tapering in both depth and width can also be formed.

The first step in the production of a sandwich-panel is mounting the outer skin in a sub-assembly jig. It is then checked to ensure contact with a set of contour templates and the corrugated core is placed in position and service-bolted to it. This assembly is removed from the jig, dismantled and given normal degreasing and etching treatment prior to spot welding. It is reassembled and the spot-weld pitch marked on the outer skin. Spot welding is carried out and X-ray examination made. When the panel has been returned to its jig the inner skin is placed in position and held there by formers. Holes are drilled through the inner skin and the corrugated core; these are then blind-riveted together. Local reinforcing details are fitted at this stage. The panel, now a rigid assembly, is removed from the jig and checked for surface finish and contour. Panels are then incorporated in major and final assembly structures.

Almost five thousand Victor parts are stretch-formed. Relatively few components are produced on conventional rubber presses. Two horizontal stretch-forming machines were designed by the company's jig-and-tool drawing office. Much complicated work is undertaken by Cricklewood's spar-milling machines, examples being wing spars and pipe-joints.

A normal vacuum moulding process is used to make the huge radome. The mould is probably the largest of its type yet made; layers of Fibreglass and Hycar are built up and cured in large ovens. Fibreglass is also extensively used for cable ducts.

Sub- and major assemblies produced at Cricklewood are transported by road to Colney Street, where they are mounted in final assembly jigs prior to equipment being installed. Victors are test-flown from Radlett. Production has now reached a peak rate, and the following facts and figures have been released: The Victor has 15,000 drawings and 40,000 detail parts; its electrical system is connected by over 40 miles of cable; it has 2,200 items of equipment supplied by the Government or outside manufacturers; more than 100 sub-contractors are involved.

Handley Page name principal suppliers of equipment for the Victor B.1 as:—

Aero Controls Ltd.; Airscrew Co. & Jicwood Ltd.; Bloctube Controls Ltd.; James Booth & Co. Ltd.; Bristol-Siddeley Engines Ltd.; British Messier Ltd.; British Thomson-Houston Co. Ltd.; de Havilland Propellers Ltd.; Dowty Equipment Ltd.; Dunlop Rubber Co. Ltd.; Dzus Fastener (Europe) Ltd.; Electro-Hydraulics Ltd.; Elliott Bros. (London) Ltd.; Fireproof Tanks Ltd.; Flight Refuelling Ltd.; G.O. Parachute Co. Ltd.; Sir George Godfrey & Partners Ltd.; Graviner Manufacturing Co. Ltd.; High Duty Alloys Ltd.; H. M. Hobson Ltd.; King Aircraft Corporation: Normalair Ltd.; Northern Aluminium Co. Ltd.; Plessey Co. Ltd.; Rotax Ltd.; Rotol Ltd.; L. A. Rumbold & Co. Ltd.; Sangamo Weston Ltd.; Saunders Valve Co. Ltd.; Self-Priming Pump & Engineering Co. Ltd.; Smiths Aircraft Instruments Ltd.; J. Stone & Co. (Charlton) Ltd.; Teddington Aircraft Controls Ltd.; Thermal Control Co. Ltd.; Titanine Ltd.; Vickers-Armstrongs (Aircraft) Ltd.

RETROSPECT

From "Flight" of March 20, 1909

The French Pupil Pilots at Work: During the last two or three weeks the trial machine used by the pupil pilots has been in hospital, and truth to tell, we should not be surprised to see one or two of the pupils themselves there before long. Only the other day, when the machine, once more itself, made its first flight of about 60 or 80 metres, M. Desvaliers took a header off the driver's seat as the result of a faulty manœuvre. He picked himself up safe and sound, however, and is now once more waiting for repairs to be effected, for it was he who put the flyer *hors de combat* on the last occasion.

As part of the environmental-test programme of the Seaslug missile, low temperatures are produced in this climatic chamber at Armstrong Whitworth's Whitley plant. Vibration, impact, pressure and humidity checks are also included in the work of the laboratory

Missiles and Spaceflight

X-15 AIRBORNE

First captive flight test of the first North American X-15 research aircraft was made from Edwards A.F.B., California, on Tuesday, March 10, with the X-15 attached beneath the starboard wing of a B-52. In the cockpit of the X-15 was Scott Crossfield, North American test pilot, who is carrying out the initial trials of the machine. Captive flights were to be followed by air-launched flights of the X-15 itself, at first unpowered and afterwards under the power of its two liquid-fuel rocket engines.

BOMARC TELEMETRY

A new type of telemetry package for the IM-99 Bomarc was recently developed and built by Texas Instruments Inc. The equipment is housed in a space 10in×14in×6in in each of the missile's wings.

For effective operation of the transistors used in the telemetry package, temperatures must be kept low. In-flight cooling is by means of a small methyl alcohol evaporator and, for extended pre-launch periods on the ground, a Boeing-designed auxiliary cooling system is used to circulate air through the equipment compartments inside the wings.

SPACE COMMITTEE-MEN

The members of the recently formed National Committee on Space Research, whose first meeting was briefly recorded in our issue of March 6, include representatives of the Ministry of Supply, Royal Aeronautical Society and the universities, in addition to strong representation from the Royal Society. Under the chairmanship of Professor H. S. W. Massey of University College, London the committee includes Prof. F. Hoyle, Prof. A. C. B. Lovell and Dr. L. R. Shepherd of the Royal Society; Sir Graham Sutton, Director-General of the Meteorological Office; Sir Arnold Hall (Royal Aeronautical Society); Dr. R. L. Smith-Rose and Mr. P. D. Greenall of D.S.I.R.,; and, from the Ministry of Supply, Sir Owen Wansbrough-Jones, Sir George Gardner, Dr. R. C. Cockburn and Dr. A. W. Lines. Prof. P. A. Sheppard represents the Royal Meteorological Society and the remaining members of the committee include the Astronomer Royal, Dr. R. v.d. R. Woolley, and the Astronomer Royal for Scotland, Dr. H. A. Brück.

Among the objectives of the new committee is co-operation with the Committee on Space Research (Cospar) set up by the International Council of Scientific Unions.

LIGHT RELIEF IN WASHINGTON—

In the absence of a reasonably intelligent schoolboy to give advice, a number of U.S. Senators and Representatives became slightly entangled in affairs of outer space on March 5 at a meeting of the House Select Committee on Astronautics and Space Exploration. Referring to the extension of national boundaries into space, Senator K. B. Keating said: "Because of the curved face of the earth, the extension would produce an inverted cone. At some point these cones would overlap and more than one State would be occupying the same airspace." Representative J. G. Fulton denied any overlap, assuming the cones were projected down to the earth's centre. "I don't project them down," replied Mr. Keating. In that case, Mr. Fulton said, if the boundaries were projected upwards like columns, not only would there not be any overlap, but there would be gaps.

But, insisted Mr. Keating, if the earth continued to rotate on its axis, the cones or columns would get mixed up. Representative J. M. Quigley then entered the discussion. He told Mr. Keating, "I throw the whole weight of my scientific ignorance on your side."

—AND AT WESTMINSTER

From *Hansard* for Wednesday, March 11:—

Mr. Ward: A pale yellow light was seen by officials at London Airport above one of the runways from 7.25 to 7.45 on the evening of 25th February. There was no corresponding response on the airport radars or on air defence radars. The light was not identified.

Mr. de Freitas: Should not the Secretary of State's Department have pointed out that there were natural conditions which could quite easily have led to this apparition, and not have given, by implication, the idea that there was some Martian saucer hovering and waiting for permission to land?

BOEING'S HOT-SHOT TUNNEL

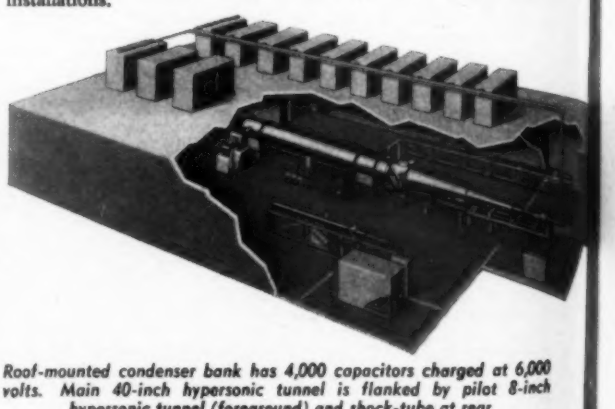
DESIGNED to stimulate flight conditions from an altitude of 150,000ft upwards, including speeds between Mach 10 and 27, a new arc-discharge or "hot-shot" tunnel is now being built by Boeing Airplane Company at Seattle. When the tunnel comes into operation later this year it will be the largest privately owned hypersonic facility in the U.S.A.

The Boeing installation, which incorporates a 40in test section, is patterned on facilities at the Arnold Engineering Development Center at Tullahoma, Tennessee, and is similar to the more-familiar "blow-down" tunnel. Instead of using compressed air, however, a high-voltage electric arc is employed.

As illustrated in the artist's impression, the 60ft hot-shot tunnel comprises an arc chamber (right) and test chamber (left), separated by a conical nozzle which has a tungsten throat. The arc chamber is pressurized to 2,000 lb/sq in and air in the test chamber is evacuated. A charge of up to five million amps is discharged across two electrodes in the arc chamber, increasing the pressure in the chamber to 4,000-30,000 lb/sq in and the temperature to 5,000-25,000 deg F.

This high pressure ruptures the plastic diaphram used to seal the throat of the tunnel, and a shockwave, followed by a brief, steady hypersonic flow, passes along the 23ft nozzle and test chamber. A typical test would take no longer than $\frac{1}{10}$ sec, during which time 36 information channels would have been recording model data. The speed of the air through the test chamber is determined by the size of the tunnel throat: for Mach 26 the throat is a small pinhole.

A pilot hot-shot tunnel of eight-inch test section has been in operation at Boeing since last August, and has been used to check out the components used in the larger version. The new facility will be the company's eighth wind tunnel, those in use at present comprising two transonic (up to M=1.3), two supersonic (M=1.2 to 4.2) and three small hypersonic (above M=5) installations.



Roof-mounted condenser bank has 4,000 capacitors charged at 6,000 volts. Main 40-inch hypersonic tunnel is flanked by pilot 8-inch hypersonic tunnel (foreground) and shock-tube at rear

Straight and Level

ASSUMING that our aircraft industry's destiny-shapers have read the recent American I.A.S. supersonic-transport lectures, can there be any who still think that Britain's initial project should have a design-speed of less than Mach 2? If there are, they might well consider three things.

The plain facts on which we must base our decision to build or not to build a supersonic airliner are as follows: (1) The Americans—probably Lockheed, who were noticeably absent from the I.A.S. lectures—will go straight for Mach 3 and they will have an airliner ready for service by 1975. (2) The project, or two, will be largely U.S. government-financed and U.S.A.F.-developed, and its progress will receive an unbeatable sputnik-impetus when the Russians fly their supersonic airliner in two or three years' time. (3) The American fund of knowledge about high-speed aerodynamics, structures, kinetic heating, systems-engineering, etc., infinitely exceeds British experience.

Only if these facts are faced shall we avoid a ghastly repetition of past mistakes. We can do a supersonic airliner, but it must be Mach 3, it will cost us at least £200 millions, and if it is to be ready for B.O.A.C. service by 1975 we must start to develop it now. There must be no toying with Mach less-than-two ideas, because such supersonics will be money thrown away.

The only alternative is to spend our money developing those types of aircraft which we can sell in the largest numbers.

● Britain's independent airline operators are always complaining about restrictions. Yet their woes appear trivial when compared with those of independent road-haulage operators.

Imagine what the air charter market would be like if the following sort of thing happened.

An enterprising private road haulier, it is reported, quoted £22 per 44-hour week for operating his six-ton tipping lorry on behalf of the Somerset County Council. This tender, which worked out at 10s per hour (others varied between 11s 6d and 13s per hour), was eagerly accepted by the Council.

The Road Haulage Association—the equivalent of B.I.A.T.A.—has since taken the trouble to produce figures showing that the haulier's quotation will lose him 13s 8d a week! The fact that the operator himself is confident of making a profit appears to be of secondary importance.

Why *are* such obstacles put in the way of enterprise? One reason, it seems, is that "There is a grave danger that the careful balance of facilities in each area, which the authorities have been at pains to build up, will be destroyed."

The same sort of enterprise-stifling "explanation" is given for the rejection of independent-airline applications to operate very-low-fare services. You know the sort of mumbo-jumbo: "These services will undermine the carefully built up international fare structure. . . ."

● There is good advertising and bad advertising, and still too much of the latter. But more commercial concerns seem to be realizing that the pulling power of the space they buy does not depend upon capital letters, crafty typography, shriek marks, and so on. Here is the opening of a recent ad. for an optical projector by Eastman Kodak, which illustrates the kind of writing I welcome:—

"This is a blade from a jet engine. Many mathematical minds, mighty mathematical machines and much aerodynamic experimentation have created its shape. Violation of the plan to the extent of a few thousandths of an inch in a single cross-section of a single blade sucks at efficiency like a little leech. And there are so many blades in a single compressor or turbine that the total number of them made in the brief span of air-breathing, non-reciprocating history must compare with all the wooden spokes in all the wagon wheels of all the supply trains in all armies since Alexander the Great . . ."

● By a curious twist of fate the swing-tail CL-44 will, I imagine, be a competitor of the Short Britannic—even though both aircraft spring from the same Bristol Britannia root (indeed both have the same wing). Does it not strike you as curious that two builders of the Bristol Britannia should now be marketing Britannia developments which are competitive? And that the parent, Bristol, has virtually no stake—except, I suppose, for royalties—in either?

Of course there will be one basic difference between the Canadair CL-44 freighter and the Short Britannic—air-dropping from the swing-tailer will be rather inadvisable.

● With what unseemly indignation did the airlines remonstrate at the recent increases in British airport charges! "Savage!" protested the Foreign Airlines Association in London.

Savage is a pretty strong word. But it is justifiable if some of the airlines which chose it had consulted with the airport authorities before buying airliners which required, at one technological stroke, twice the amount of concrete, twice the Customs and health and immigration and baggage-handling capacity, and twice as speedy A.T.C. clearances as are needed by the airliners which they are to replace. Did they do this?

● A most embarrassing thing happened during the 50th anniversary celebrations of Scruggs Aircraft at the Air Power Club last week.

The chairman, Sir John Blackout-Jones, was just coming to the end of a three-hour reminiscence about what he called "the good old days" (including 23 anecdotes about the flying exploits of the founder, old Henry "Scruggsey" Scruggs himself) when in burst the firm's sales director, Mr. Julian Washbrain, in a state of great agitation.

Blackie, who was in the middle of the famous wing-walking story, looked furious. "What the devil is it, man?" he snapped.

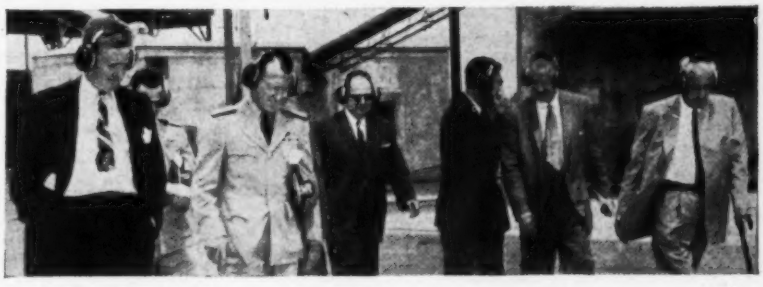
There followed a whispered exchange during which Blackie's face assumed an expression of excited incredulity. Swallowing hard, he spluttered: "I am sorry, but Washbrain here tells me we have just received an order. I must get back at once."

● Inaugural flights to the Continent usually have their moments. The other day, at one of those admirable luncheons which *syndicats d'Initiative* are liable to organize at the drop of an undercarriage, a hurrying waiter let fall an unopened bottle of *vin rosé* squarely on the head of a charming young woman executive of the airline company. Instantly and gallantly, in excellent English, he said: "So sorry, mam'selle—but eet ees only a light wine."

A colleague of mine who was there is still wondering if that waiter does it every day, once having found that the resultant laugh fulfils his ego.

ROGER BACON

A lecturer at the American supersonic-transport symposium said that, because there could be no windows at Mach 3, passengers would have to be provided with television. I suppose they will get used to it, just as those of us on the ground will get used to walking about like this



AIR COMMERCE

The Munich Accident

LAST Friday, more than a year after the event, the report* was published of the German inquiry into the accident to B.E.A. Elizabethan G-ALZU at Munich on February 6, 1958, in which 22 of the 44 occupants lost their lives. The accident occurred during the third attempt of the aircraft to take off from Munich-Reim Airport for London, two previous attempts having been abandoned due to fluctuations in boost readings.

In tracing the causes of the accident, the comprehensive German report deals first with eventualities that could be eliminated.

The detailed text is confined to the effect on rolling friction of snow on the runway, the effect of slush on the free running of the wheels and the effects of wing icing on take-off performance.

The Elizabethan had landed at Munich after a flight from Belgrade in which it had been subjected to cold-soak at −21 deg C to −25 deg C; during the two hours the aircraft was at Munich ground temperatures were at or a little below freezing and there were moderate to slight falls of snow. By 1600 hr, when -ZU taxied out for the last time, about 1½in to 2in of snow had fallen and the runway was covered with a ⅛in-¼in deep layer of slush.

Dealing first with the rolling friction on the runway, the commission was advised that as a result of the slush take-off distance would have been increased by about 360ft at the most. Captain James Thain, the senior pilot, who survived the crash, said that he was satisfied with the condition of the runway. The report concluded that "slush on the runway did not increase the rolling friction to such an extent that the accident could be attributed to this."

Nor did the commission believe that the slush effected the free running of the wheels, although in a statement appended to the report Capt. Thain attributes the accident to this.

On the final take-off, acceleration appeared normal up to the V_1 (take-off decision point) speed of 117 kt. "The needle of the A.S.I.," noted Capt. Thain in his account, "was flickering slightly, and when it indicated 117 kt I called 'V_1' and waited for a positive indication of more speed. Capt. Rayment [the pilot-in-charge who died as a result of injuries sustained in the accident] was adjusting the trim of the aircraft . . . The needle hovered at 117 kt and then dropped 4 or 5 kt, I was conscious of a lack of acceleration, the needle dropped further to about 105 kt and hovered at this reading . . ."

Consideration is given in the report to snow or slush jamming between the wheels and hindering their rotation, but "since not a single indication came to light" the possibility "appeared extremely remote."

In investigating the effects of wing icing, the commission were influenced by evidence that, when the wreckage was examined six hours after the crash, a layer of rough ice, about ⅛in thick, was found under the snow on the wings. On a basis of calculation, this deposit could have been formed from the snow that fell while the aircraft was standing on the ground.

Both pilots were in agreement that nothing need be done about the snow; Capt. Thain said that he saw only melted snow running off the trailing edges of the wings. But, in the words of the report: "The pilots had at no time such a view over the wings as would have permitted them to judge the condition of the upper surfaces of the wing reliably . . ." The snow which fell directly after the aircraft landed might have run off the wings at first and perhaps melted at the outset, but must very soon have begun to cling.

The resultant decrease in maximum lift coefficient and rise in profile drag is considered by the commission to have been a cause of the accident.

But this conclusion was not established with "complete certainty," as it did not explain Capt. Thain's observation regarding the drop in speed. Coupled with skid marks from all four landing wheels on the last part of the runway, the drop in speed "would then have the perfectly natural explanation . . . that Capt. Rayment saw disaster approaching and braked the landing wheels sharply."

If this were the case, the report comments, "it is not out of the question that a misunderstanding between the two pilots played a part at this juncture, for, whereas Capt. Rayment (probably) applied the brakes, Capt. Thain, in the hope of averting the catastrophe . . . did exactly the opposite . . . and pushed the throttle lever forward as far as possible."

This does not alter the fact, the commission states in conclusion, that the aircraft would normally have become airborne long before this and the accident would not have occurred if the aircraft had not iced-up.

Civil Aircraft Accident: Report by the Federal Republic of Germany relating to the inquiry into the accident to G-ALZU A.S.57 Ambassador (Elizabethan) on Feb. 6, 1958, at Munich-Rheim Airport, H.M.S.O. 6s.

ROUND-THE-WORLD DOUBTS

THE words "Subject to Government Approval" often appear, in extremely small type, at the foot of advertisements announcing new air services. Approvals, usually, are a mere formality.

But when these words appeared in B.O.A.C.'s recent announcement about round-the-world services they signified something more than a formality. In fact, as *Flight* goes to press, it is not at all certain that the trans-Pacific link in B.O.A.C.'s round-the-world service will receive American approval before the deadline date of April 1.

The U.S.-U.K. bilateral air agreement, reviewed two years ago, provides for a B.O.A.C. route-extension from San Francisco to Hong Kong. Therefore, so far as the U.S. State Department is concerned, B.O.A.C. can operate that route. However, according to American procedure, the C.A.B. first has to grant B.O.A.C. a foreign air carrier permit—and before it does so other airlines can object.

One airline, Northwest, which operates from Seattle across the North Pacific to Tokyo, has in fact objected to B.O.A.C.'s proposed service—on the grounds that it includes Tokyo. Northwest's objection is made on a technical point of air-agreement interpretation—namely that Tokyo is not an "intermediate point."

The U.S.-U.K. air agreement allows B.O.A.C. to include "intermediate points" on the Hong Kong - San Francisco service; and B.O.A.C. are said to have agreed, during the revision of the bilateral, that "intermediate point" means a minor traffic stop. Northwest contend that Tokyo, as the most populous city in the world, is hardly a minor traffic stop. The airline feels that the B.O.A.C. service will divert its Tokyo-U.S. business.

Meanwhile, B.O.A.C. appear to be proceeding as if April 1 will —as advertised—see the opening of their round-the-world service.

Turboprop partners for Ansett-A.N.A. are the Viscount 810 and the Electra: the first of each species respectively came off the Vickers and Lockheed lines at about the same time. The Australian airline has ordered four Viscounts and two Electras. The Viscount left Weybridge for Melbourne last week

AIR COMMERCE . . .

Sharing the North Atlantic Cake

THREE features of the North Atlantic market in 1958 stand out prominently: for the first time ever, air traffic exceeded sea traffic; and for the first time in any year scheduled traffic exceeded one million passengers and total traffic carried by all airlines rose to an all-time record of some 1¼ million passengers. Yet, despite these traffic gains, profits probably fell to an all-time low.

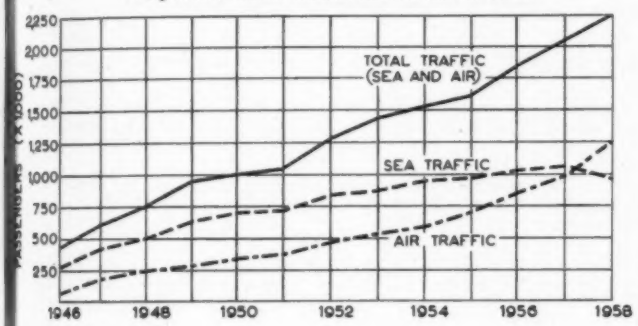
The bare facts for 1958—as outlined in *Flight* for February 20—were that air traffic increased by 23 per cent. (As seating rose by as much as 35 per cent, seat load-factor fell from 67 to 61 per cent.) Sea traffic, on the other hand, dropped by 10 per cent.

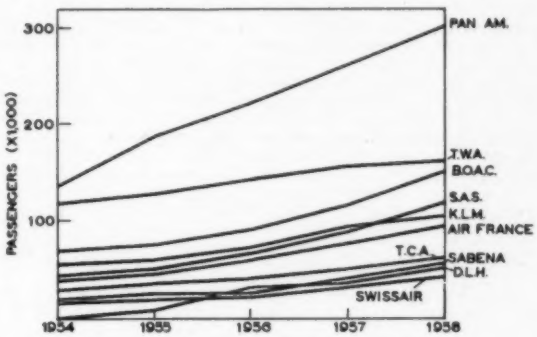
Total sea and air traffic across the North Atlantic has increased at a fairly steady post-war rate of 15 per cent per annum. But air traffic over the past four years has accelerated to an annual growth rate of 20 per cent while sea traffic has tailed off. European airlines have participated most favourably in this increased market for air travel, the share of the North American carriers having declined to 46 per cent. With the exception of the two years 1954 and 1955 (when B.O.A.C. traffic was depressed as a result of equipment shortage), the North American share of the North Atlantic market has fallen steadily throughout the post-war period. In the last few years this has been a reflection on the slow rate of growth experienced by T.W.A. rather than on a rapid development by the European carriers.

Two of the major European airlines—B.O.A.C. and S.A.S.—have done particularly well of late, and if recent trends continue the British carrier should soon supplant T.W.A. as the No. 2 North Atlantic carrier. It is possible, indeed, that B.O.A.C. are overtaking T.W.A. just about now.

Among the smaller airlines, Alitalia L.A.I. and El Al did remarkably well last year, each more than doubling the previous year's level of traffic. Two new carriers—Aerlinte Eireann and Qantas—appeared on the Atlantic in 1958. The Irish airline moved quickly to capture as many as 11,000 passengers in their first year's operation; but their load factor, alas, was only 38 per cent. The Irish airline may have lost nearly £1m (see the following page: "Boeing 720s for Aerlinte").

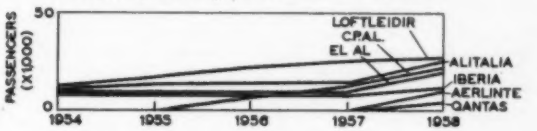
The growth of North Atlantic and sea and air traffic





Above, comparative growths of the "big ten"

Below, comparative growths of the "small seven"



A DAY WITH THE BURGHERS

WHEN Air Charter's DC-4 G-ANYB (Capt. R. Langley) and Mk 32 Bristol 170 G-ANVS (Capt. H. McDonnell) touched down on Calais-Marck's new 4,300ft runway on March 10 they initiated what looks like being a record-breaking experiment of allowing foot passengers (so to speak) to use the Channel Air Bridge. In other words, the Home Office having recently given its blessing to no-passport day trips by air, the company had decided to utilize vacant seats in their nine car-carrying Freighters for the purpose; and so instantaneous and overwhelming was the response that they have had to press one of their three trooping DC-4s into service to take the overflow, the lengthening of the Marck runway now making this possible. By the date of last week's inaugural service they had already accepted nearly 9,000 reservations. Some 75 per cent are for staff outings, from London and from provincial areas.

Subject to seasonal variation, services will leave Southend at 0800, 0940 and 1120 hr, returning from Calais at 1720, 1900 and 2040. London passengers leave Euston Coach Station, have a 90-min run to Southend Airport and pay 77s 6d for the return trip, while those who start from Southend pay only 70s (plus, in each case, the usual 2s airport tax, looming annoyingly large in relation to such modest fares). Air Charter advertise "special arrangements for staff outings and works parties."

They have also entered into an agreement with the General Steam Navigation Co. whereby the trip can be outward by air and home by sea or (clearly a headache for the traffic staff) *vice versa*. Return by sea should also simplify the problem presented by the occasional day-tripper overcome by the delights of Calais—though Air Charter expect little trouble of this kind, especially if all their passengers are as eminently respectable as those of last week.

The Freighters have been fitted for up to 24 seats, and the DC-4, which will be put on when necessary, for up to 74. As *Flight* found on the inaugural trip with 70 rearward-facing seats in the four-engined aircraft this is no hardship on a 28-minute (chock-to-chock) haul. Airborne time for the crossing is in the region of 21 minutes.

On this first trip the DC-4 was occupied mainly by Fleet Street; in the Freighter were 21 genuine passportless passengers, who emerged at Calais-Marck to find themselves the centre of a full-scale flowers-and-flashlights reception, with civic hospitality to follow for the rest of the day.

At the Transport Ministry on March 9 the Joint Parliamentary Secretary, Mr. John Hay, presented Queen's Commendations for Valuable Services in the Air to (l. to r.): Capt. P. J. McKeown, B.E.A., training captain, Viscount 802s; Capt. H. J. Field, B.O.A.C., special duties; Mr. C. W. Rodgers, B.E.A., senior radio officer; Capt. A. Meagher, B.O.A.C., deputy flight manager, Britannia 312s; Mr. R. Miller, B.O.A.C., senior radio officer

AIR COMMERCE . . .

The first of a fleet of 15 Boeing 707-120s recently delivered to T.W.A. is seen here at New York International. The airline will begin non-stop New York - San Francisco jet services today, March 20. Note the new markings, a red arrow-head down the side of the fuselage, and company initials only above it. North Atlantic T.W.A. jet operations will probably await delivery of the first of eighteen 707-320s later in the year

BOEING 720s FOR AERLINTE

AERLINTE'S order for three Boeing 720s (briefly referred to last week) has now been confirmed, following the Irish Government's approval that Aerlinte should operate jets. Services on the North Atlantic will begin in early summer, 1961. It was left to the Minister of Industry and Commerce, Mr. Séan Lemass (in consultation with Aerlinte) to decide what type of aircraft and associated equipment will be bought with the £5½m or £6m which (it is said) will be invested in the fleet.

There appear to be three factors governing Aerlinte's choice of the 720. At £1.2m each the price is appreciably less than that of a Boeing 707-120, while the speed of the lightest version of the Boeing 707 family is only just below that of the Convair 880. The aircraft is also claimed to be economical over stage-lengths as low as 175 n.m., although this would seem to be of academic interest for an aircraft used, say, on a route pattern Chicago - New York - Boston - Shannon - Rome - Ruhr - Zurich. (Aerlinte are also anxious to attract North Atlantic traffic originating in Middle East and Asian areas.) Boeing quote the maximum range of the 720 with a full payload of 33,000 lb and 13,000 lb reserve fuel as 2,300 n.m., so that payload on the 2,668 n.m. Shannon - New York stage would be limited by fuel weight. With a total tankage (including maximum optional fuel) of 11,221 Imp. gal. and the same reserve fuel, the payload would be about 26,000 lb.

It is not intended to use Aerlinte's jets between Shannon and Dublin, and these local services would be operated (as they are now) by Friendships and Viscounts and thence into the Aer Lingus' European network.

Aerlinte has now been operating for just under 12 months. During the peak months of July, August and September 1958 the airline is reported to have carried 4,471 westbound passengers at a load factor of 54 per cent and 2,437 eastbound passengers at 29 per cent. It carried more passengers than El Al, Iberia or Qantas over the three months of July, August and September.

The overall load factor for the seven months of 1958 was 38 per cent. No financial statements have been issued, but the loss on the first year of operations seems likely to be between £¼m and £1m. This estimated deficit must be compared against an annual national income of less than £150m.

BREVITIES

The Handley Page Dart Herald is due to leave on its demonstration tour of Europe, Asia and Africa in early April. Among the places to be visited, it is understood, are Athens, Ankara, Teheran, Karachi, Delhi, Lahore, Bangalore, Bombay, Aden, Addis Ababa, Central Africa and West Africa.

* * *

A Sao Paulo financial group is reported to be discussing possible manufacture of the Hurel-Dubois H.D.32 in Brazil.

* * *

The I.A.T.A. Clearing House in London settled more than £292m in 1958, 28 per cent more than in the 1957 record year. Cost to I.A.T.A. members was about 3½d. per £100.

* * *

The eighth and last Douglas DC-8 for K.L.M. will be named *Sir Frank Whittle*. The first one will be *Albert Plesman*, and the second *Anthony H. G. Fokker*.

* * *

The Vickers Vanguard completed 50 flying hours in the 50 days following its first flight on January 20. The aircraft has been flown pressurized to 26,000ft, at up to 250 kt and at 131,000 lb take-off weight.

* * *

The memorial to Alcock and Brown being erected at Clifden, Co. Galway, by Aer Lingus, will be unveiled on June 15 this year, the fortieth anniversary of the day the airmen put down their Vickers Vimy in a bog near Clifden after their transatlantic flight.

* * *

Statistics issued by the Helicopter Council of the U.S. Aircraft Industries Association list 535 helicopters in commercial service in the U.S.A. and Canada. Of these, 400 are Bell 47s and 78 are Sikorskys; there are 26 Hillers, 21 Vertols, five Alouettes, three Kamans and two Westlands. A further 100 Bell helicopters have been delivered to private operators.

B.O.A.C. has appointed Mr. Clyde M. Culpepper as resident sales representative, Houston, Texas. Mr. Culpepper, an American, was formerly Eastern Air Lines' traffic manager at Houston.

* * *

Trans-Canada Air Lines are now using the name "Air Canada" for promotional and advertising purposes on the Continent of Europe.

* * *

U.K. air traffic in January 1959 was 15 per cent greater than in January 1958—22.6 million l.t.ms. Load factor remained unchanged at 54 per cent.

* * *

Total number of civil aircraft registered in the U.S.A. last year was 98,414. This was broken down as follows: scheduled airlines 1,834; private aircraft 95,577; miscellaneous 1,003.

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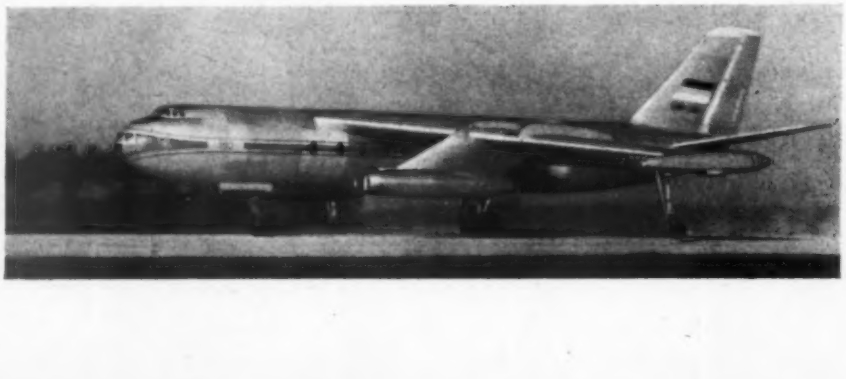
The M.T.C.A. announced on March 11 that Mr. J. E. Hampson has been appointed to succeed Mr. L. J. Dunnett as a Deputy Secretary, the appointment to take effect from April 1.

* * *

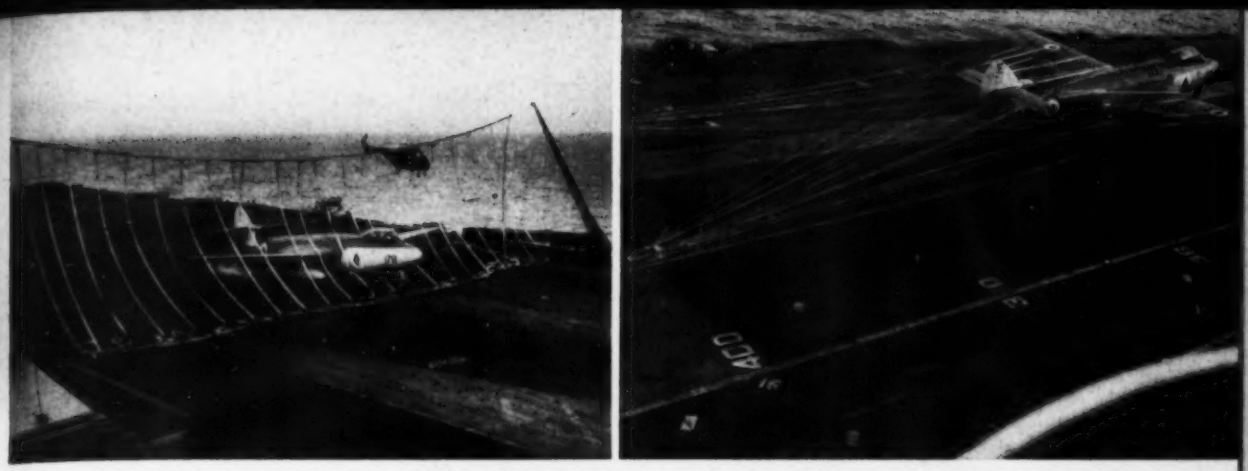
Following the purchase by the Ceylon Government of 76 per cent of the capital of Air Ceylon, the Chinese will probably grant the Ceylonese traffic rights. When negotiations on this question began, China asked for "clarification" of the fact that 49 per cent of Air Ceylon's capital was held by K.L.M.

* * *

The Viscount 810 accepted by Ansett-A.N.A. (and delivered on March 13—see picture on p. 376) will be a "full fuel, full payload" aeroplane. It was certificated at 72,500 lb, an increase of 3,500 lb above the previous 810 weight. All new 810s will gross 72,500 lb; and retrospective changes to existing aircraft can be made to bring them up to this weight (via an interim 71,000 lb, pending delivery of new brakes).



This is one of two prototypes of the BB.152 (four Pirna 014 turbojets of 6,950 lb thrust each), Eastern Germany's 57 to 72-seat Caravelle-competitor. One of the two aircraft crashed on March 4; no details of the accident are available. Strongly promoted at the Leipzig Fair, the 152 will be in airline service with the East German airline (now named Interflug) next year



Stretching things a bit when Lt. N. G. Grier-Rees of No. 806 Sqn. landed his Sea Hawk without its arrester hook on H.M.S. "Eagle" in the Mediterranean recently (see story below). At left, the aircraft is entering the nylon barrier and at right, brought to a halt in 150ft

SERVICE AVIATION

Royal Air Forces and Naval Flying News

Royal Review

THE Duchess of Gloucester is to be the reviewing officer at the passing-out parade of 33 aircraft apprentices of the 83rd Entry to No. 1 Radio School at R.A.F. Locking, Somerset, next Tuesday (March 24). She will also inspect the station's new Y.M.C.A. building and see a workshop block, models made by the apprentices, and an airman's married quarter.

On and Off

INTENSIVE flying trials were recently carried out aboard H.M.S. *Centaur* in Lyme Bay by two D.H. Sea Vixens from "C" Squadron at Boscombe Down, flown by Naval pilots. Between them, the two aircraft completed a programme of 166 deck landings, which included a number made at dusk. A Trials Flight, No. 700Y, was formed at R.N.A.S. Yeovilton last autumn to work up the Sea Vixen for squadron service in the Fleet Air Arm.

Coming Home

AFTER being Senior Technical Staff Officer at the Far East Air Force since June 1956, A. Cdre. G. N. E. Tindal-Carill-Worsley is returning to this country to be Director of Technical Training at Air Ministry with effect from May. He succeeds A. Cdre. J. R. Mutch, who is retiring from the Service. A. Cdre. Tindal-Carill-Worsley, who prior to going to the Far East commanded No. 1 School of Technical Training at R.A.F. Halton, is an armament specialist. While at Halton he initiated the construction of the Halton racing car.

Nylon S-t-r-e-t-c-h

WHAT is believed to be the first emergency Sea Hawk landing involving the use of the Royal Navy's nylon rope barrier occurred on February 28, when Lt. Nigel Grier-Rees of No. 806 ("Ace of Diamonds") Sqn. landed his Hawk on H.M.S. *Eagle* following hydraulic failure. With the aircraft's powered controls out of action he returned to the carrier's circuit and discovered that his arrester hook could not be lowered. Two touch-and-go landings were made in an unsuccessful effort to jerk the hook down, after which the nylon barrier was erected by the flight deck crew in the record time of 2 min 20 sec.

As shown in the photographs above, the Sea Hawk was arrested successfully by the barrier and, in the words of an Admiralty announcement, "both pilot and aircraft were undamaged."

Economical Stoppages

ARRESTER barriers installed at R.A.F. Gutersloh in Germany have five times during the last six months saved aircraft from overshooting. Two of these "operational engagements" occurred when a take-off had to be abandoned, and the others on landing. Each installation costs £10,000, and with aircraft costing anything from £120,000 each it is reckoned that the saving of the first three aircraft at Gutersloh alone has already more than paid for the cost of installing barriers at the remaining airfields in the Command, not to speak of the saving in pilots' lives.

Naval Air Plans

REFERENCE, to the Royal Navy's growing need for helicopter pilots was made by the Parliamentary and Financial Secretary to the Admiralty, Mr. Ian Orr-Ewing, when he introduced the Navy Estimates for 1959-60 in the House of Commons on March 9. He said that in order to meet this need a new five-year short-service commission was being introduced for pilots who would be trained specifically for helicopter duties. [In his explanatory statement on the Estimates the First Lord, the Earl of Selkirk, had said that a number of front-line squadrons of Whirlwinds had been formed in the anti-submarine rôle.]

Mr. Orr-Ewing also said that the new aircraft-carrier *Hermes* would be doing trials this summer and was expected to join the Fleet early next year. Her design and equipment, including radar, were fully up to date; and she would be equipped to carry all the new family of aircraft—the Scimitar, Sea Vixen and eventually the NA.39—as well as A.S. helicopters.

C.F.S. Reunion

THIS year's reunion dinner of the **Central Flying School Association** is to be held in the officers' mess at R.A.F. Little Rissington on Friday, July 10. Full particulars will be circulated to all members, in due course, by the honorary secretary (F/L. J. R. Aitken).

Bristol U.A.S. Dinner

ON Friday, May 15, the Bristol University Air Squadron is holding its sixth annual dinner. This will be at the Hawthorns Hotel, Woodland Road, Clifton, Bristol, at 7.30 for 8 p.m. All members and ex-members are invited to attend and should contact the Mess Secretary, Officers' Mess, Bristol U.A.S., 12 Whiteladies Road, Bristol, 8.

IN BRIEF

Five members of the R.A.F. Institute of Aviation Medicine are to attend the Aero Medical Association meeting in Los Angeles from April 27 to 29. The party will be headed by G/C. H. L. Roxburgh, deputy officer commanding the Institute and an expert on high-altitude protection.

Air Vice-Marshal H. V. Satterly, A.O.C. No. 64 Group, presenting to Mr. F. A. Chapman of Short Brothers and Harland Ltd. a propeller blade of the last Spitfire to fly operationally for the R.A.F. This aircraft, a P.R.19 (PS 853), was operated by Shorts on meteorological flights. One of the company's Mosquito T.T.35s is seen as background to the presentation ceremony held recently at R.A.F. Woodvale

Griffon II and Turbo-ramjets

TECHNICAL DIRECTOR OF NORD-AVIATION DELIVERS TWELFTH LOUIS BLÉRIOT LECTURE

THIS year's Louis Blériot Lecture, entitled *The Griffon and the Future of the Turbo-ramjet Combination in the Propulsion of Supersonic Aeroplanes*, was delivered before the Royal Aeronautical Society in London on Thursday of last week by Ingénieur Général de l'Air Noel Daum, technical director of Nord-Aviation. In the chair was the president of the R.Ae.S., Sir Arnold Hall.

Gen. Daum first dealt with some of the problems involved in operating turbojet and ramjet engines at speeds between Mach 2 and 4 and then reviewed progress with the Nord Griffon II which, appropriately enough, recently raised the 100 km closed circuit record beyond 1,000 m.p.h.

The lecturer first paid tribute to the many years of inspired work of Leduc in developing the ramjet and noted the longstanding interest of the French Government in such powerplants. Nord had themselves started work along the same lines in 1953, at which time the company already maintained two divisions specializing respectively in high-speed flight with the Gerfaut and in ramjet design for aircraft and missile applications. The speaker was considering speeds between M2 and 4, because the latter value had already been obtained by ramjets made by Nord and Mach numbers between 2 and 3 were being planned elsewhere for bomber and transport applications.

Considering first the primary elements, the turbojet with afterburner might be considered as a ramjet with an additional cycle. As Mach number increased, intake temperature rose rapidly while turbine inlet temperatures and r.p.m. limits remained fixed. Viewed as an additional cycle for a ramjet, the turbojet might therefore become a handicap at a Mach number optimistically calculated at 3.3. Additional difficulties arose in attempting to produce a turbojet which worked well throughout such a wide speed-range. With fixed-geometry compressors, turbojets ceased to act as pressure amplifiers beyond M2.7. Raising turbine temperature by 100 deg C gave an increase of only M0.25. The addition of variable stator vanes could raise the limit slightly beyond M3.

Under these conditions the intake had to be considered as an integral part of the powerplant; and the standard definitions of intake efficiency were not easy to reproduce in actual installations. The speaker showed some of the efficiencies, at their matching points, of pitot (normal shock), plain cone with 30 deg half angle (oblique shock plus normal shock) and isentropic (progressive external compression and normal shock wave). In addition, sub-critical and supercritical operating regimes arose where engine demand was below or above the intake design case. An intake could be matched to a lower Mach number and part of the intake flow diverted overboard at higher values. Variable-geometry intakes could be designed to ensure operation in the sub-critical range but they involved mechanical complications and some loss in efficiency. For a wide range of Mach numbers variable geometry both in the intake and in a bleed system could be required.

A further intake characteristic was that of external drag formed by loads exerted on the cowling itself and on the flow ahead of the intake. High efficiencies at high Mach numbers were associated with high drag at low numbers. These considerations assumed use of a variable exhaust nozzle to help in controlling turbine-inlet temperature.

Turning to the ramjet, Gen. Daum noted that variation of the exhaust nozzle area directly affected airflow at the intake and allowed this to work permanently under matched conditions. The air intake determined the quality of the ramjet. An intake matched for high Mach numbers had high external drag at low Mach numbers, and some form of compromise was desirable. If the nozzle area were fixed sub-critical conditions occurring below the design Mach number might cause surging.

The Turbo-ramjet

A turbojet giving high thrust at low speed paired with a ramjet matched to high Mach numbers was not the ideal and Nord had improved upon this by employing a common air intake for both engines. With a variable-area ramjet nozzle the compressor no longer imposed its law on the common air intake and could make full use of the high intake-efficiency provided for the ramjet. The airflow requirements of the turbojet and ramjet, characterized respectively by the local Mach numbers at the compressor-entry and combustion chamber-entry, varied in inverse direction as the flight Mach number varied. Because of this it was always possible to prepare a fixed air intake with good efficiency, in which matching to the total airflow would remain correct over a wide range, allowing, if need be, an acceptable variation of the exhaust nozzle area. Thus it was possible to achieve the sum of the thrusts of a turbojet without intake losses and of a well-matched ramjet without the complication of two variable intakes. Because the variation in total airflow co-efficient was lower, even the provision of a variable intake for this turbo-ramjet would be relatively easy.

When saving weight and accepting reduced performance, a turbo-ramjet with fixed intake and nozzle could be acceptably matched for cruising Mach numbers up to 3. For cruising at maximum Mach number, according to a Bréguet type of trajectory, s.f.c. was a fundamental characteristic of the powerplant. At Mach 2.5 to 2.8 the s.f.c. of the ramjet alone became lower than that of the turbojet alone. At speeds of this order intake design became critical in determining s.f.c. and this was of the order of 2.3 lb/lb/hr both for either turbojet or ramjet. As Mach number decreased, the s.f.c. of the turbojet went down while that of the ramjet increased. At M2 they might be respectively 2.2 and 2.5; and a turbo-ramjet combination would give about 2.35. At M1.5 ramjet s.f.c. would rise to 2.8, the turbojet would drop to 2 and the turbo-ramjet would stay at 2.35.

A reduction in the weight of the engine would, with a constant fuel load, allow longer range at the same s.f.c. Acceleration and climb phases were constrained by speed and structural conditions to a pattern comprising acceleration low down to M0.9, followed by climb at a constant M0.9 to somewhere below 36,000ft; near-level acceleration to an airframe-limited speed (say 700 kt); climb at constant aerodynamic loading to maximum Mach number; climb at M_{max} to cruising height.

If the chosen thrust were too high, the engine would be large and heavy, but if excess thrust were too small excessive fuel would be used during the climb. The size of the turbojet would therefore have to be "optimized." If a turbojet alone were chosen to suit a climb at a high Mach number, allowing a margin for manœuvring, or to give minimum s.f.c., the engine would have excessive thrust in the transonic region and would be large and heavy. If the engine were scaled for climb and cruise together, it would again turn out large and heavy; and in both cases there would be superabundant thrust for take-off.

Balancing the Sizes

In the turbo-ramjet combination the proportion of thrust provided by each element could be adjusted, as well as the type of ramjet. Excess thrust could be large in the high-supersonic range and small at the transonic. The turbojet would then be small. High ramjet s.f.c. would be compensated by short supersonic-acceleration period and total weight of powerplant and fuel during climb would be less than that for a large turbojet. A large cruising-thrust margin would allow reduction of mixture strength to provide a minimum s.f.c. Reduction of drag coefficient by application of area rule might allow a further decrease in the size of the turbojet, but sufficient thrust should be retained for take-off.

Gen. Daum then said that the great advantage of the ramjet was its lightness resulting from lack of moving parts, low internal pressures, cooling by air at ambient stagnation temperature and the possibility of greatly simplifying the engine. There were other advantages. For example, the internal contours of the ramjet could be simply changed during construction or even after the aircraft had flown, so that changes in overall drag of the aircraft or in the specification could be accommodated. Neither was it necessary to use a turbojet designed for the maximum Mach number. A "slower" engine could be installed and shut down after its own Mach limit had been reached. It would then idle to provide shaft drive for accessories. Because the turbojet was housed inside the ramjet it remained in a subsonic environment, both intake and efflux being located in airflow-zones at M0.4 to M0.5. The development time for the turbo-ramjet was surprisingly short.

The lecturer referred to other "turbo-ramjet combinations" such as the bypass engine which, he said, was intended to allow the afterburner element to operate effectively at a higher Mach number. Besides being cumbersome, this solution lost the major advantage of lightness.

The Griffon II

Gen. Daum next turned to the Griffon II itself, noting that an official order for such a machine was placed only late in 1953. In two stages, the aircraft was first to fly with an afterburning SNECMA Atar F and no ramjet, after which a ramjet was to be disposed about a SNECMA Atar E3 (7,700 lb thrust). It had already been decided to test a small turbo-ramjet built round a Turboméca Palas, but first a scale model was tried based on a combustion chamber of the Sud Ariel helicopter. Both these units were extensively tested at Gatines and Modane, the Palas unit reaching M0.8 in free stream at Modane in 1954. A rather unusual type of surging in the Palas was cured in 1955 although the effect was not entirely satisfactorily explained. In the spring of 1956 an Atar E3-based turbo-ramjet was tested at Modane, its systems and controls finalized and the best arrangement to reduce losses at take-off established. The "cold" drag of the ramjet was determined, and by November the full flying version of the turbo-ramjet was tested. The decision to equip the second Griffon directly with the turbo-ramjet unit had already been taken. First flights followed in January 1957; the ramjet was first lit in April ; and M1 was exceeded in May. M1.85 was attained at 42,000ft, surplus thrust still sufficing for a climb of no less than 28,000ft/min at that point. Further Mach increases were slow because the limits of the turbojet were being approached, but the M2 area had become routine by last October, the turbojet being throttled back at M1.8. Kinetic heating at present limited extension beyond the M2.1 and 61,000ft (still accelerating) so far reached.

The Griffon II grossed 15,000 lb, of which the complete powerplant (including ramjet structure, accessories and the aft fuselage shell enclosing them) accounted for 3,740 lb. Ramjet diameter was 4.5ft, affording more than 80 per cent of total thrust at Mach 2—9,200 lb at 50,000ft and 5,500 lb at about 60,000ft.

Several French and foreign pilots had flown the Griffon II and remarked on its smoothness and the insensitivity of its intake system to high incidences. Acceleration could be maintained in turns and this largely accounted for the 100 km closed-circuit record performance. Deliberate extinction of the ramjet did not disturb the turbojet. Ramjet fuel/air mixture could be varied in flight. Thrust loss on take-off was less than that of a plain turbojet; the ramjet could be lit over a wide speed range and there was no unfavourable interaction between the two engines.

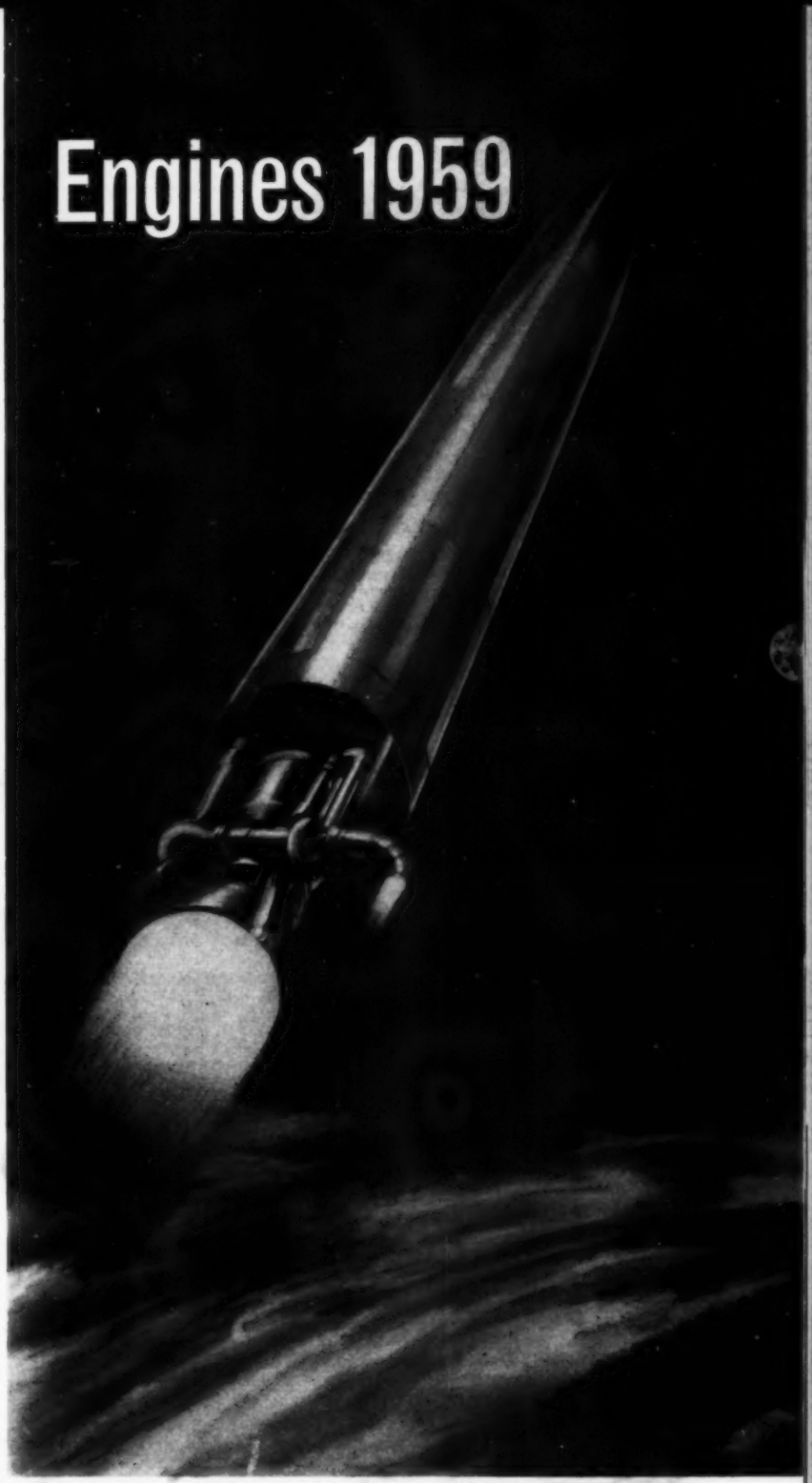
Nord continued to investigate applications including turbo-ramjets for boosting airliners to supersonic speed, and the mounting of one or more turbojets in a flat ramjet whose intakes could be located beneath a wing and allow substantially improved L/D. Nord had designed a Griffon derivative with a more powerful turbojet and predicted "with absolute confidence" a speed over M3 at 66,000ft to 80,000ft.

In conclusion, Gen. Daum stated that the turbo-ramjet with a 30 per cent saving in powerplant weight could lead to a 20 per cent increase in range or a doubled payload for large, long-range aircraft.

Aero Engines 1959

THE PROPULSION SPECTRUM

Some Thoughts on Flat-Sixes and Photon Sails

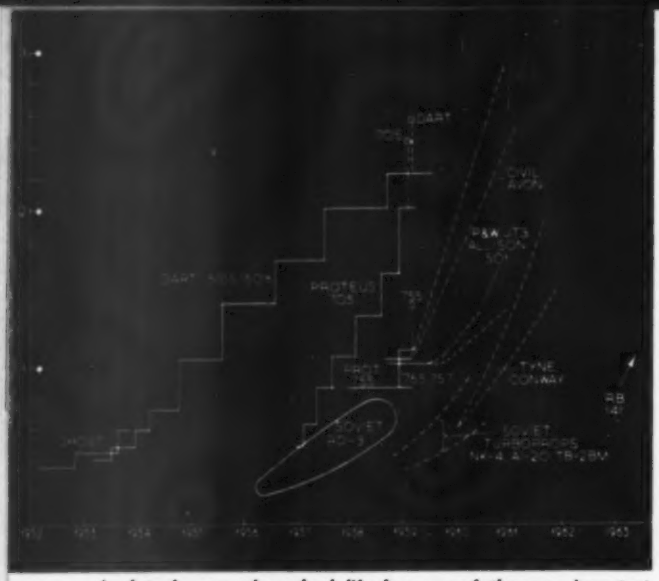


An impression by a Rocketdyne artist of a vehicle propelled by a nuclear rocket engine

ANY chronicler of the history of mankind does well to view his subject against the broader background of the history of the Universe, or even of our own Earth. It is then apparent that man, and even life itself, has existed only during the most immediate past, and his history represents but a trivial slice of the overall period. By the same token, a reviewer of the field of flight propulsion should not dwell too long on what has already been accomplished. One has but to plot a few curves to appreciate that man is on the brink of the biggest quantum jump in flight performance that there has ever been or ever will be. The past is embryonic.

Most of us are familiar with present-day flight speeds, and can compare them with the corresponding figures of twenty or forty years ago. But all such data are for vehicles gripped by the Earth's gravity and restrained by the clutch of the surrounding air. It has taken a little more than half a century to progress from the first, tentative step off the ground to the first—equally tentative—step off the Earth. The way is now open to the achievement of speeds ten, a hundred, a thousand times greater than any previously reached by man. And such speeds will be very necessary, because once one is freed from the Earth, the distances involved are enormous.

In this article it is proposed to take stock of the propulsive requirements of a wide range of flight vehicles. Such an essay is today only marginally possible, and will shortly become impracticable. Ten years ago the term "flight vehicle" was virtually restricted to fixed-wing aeroplanes; then the only major propulsive argument centred upon the introduction of the gas turbine, and the big question was merely "to what extent will the gas turbine displace the piston engine?" Today the reviewer is confronted with a field of awesome extent. What will drive the future STOLs and VTOLs? What species of engine will best fit the flying platforms and zero-pressure vehicles? How about the next generation of airliners—or ballistic missiles? And, by no means least, how will propulsion and control be achieved in the awesome fastness of outer space? It is evident that the problem must be broken down into manageable sections.



A plot of approved overhaul life for some of the more important commercial gas turbines. The relative steepness of the projected curves for the civil Avon and Tyne stems largely from Dart experience, and the 1,000-hr start of the JT3 and Allison 501 rests on extensive military operations

AERO ENGINES 1959 . . .

Light Aircraft

Notwithstanding the increasing onslaughts of its competitors, the piston engine is the unchallenged master in this field, and is likely to remain so for at least another decade. It is, in any case, hardly fair to assess the situation in a dispassionate manner, since in this field the factor of finance is absolutely predominant.

Any organization wishing to develop an optimum 1959 piston engine of from 50 to 150 h.p. must be prepared to spend up to £250,000, and certainly at least £100,000. If a company were to take such a step the money would probably be recovered in sales within five years, since the resulting powerplant would be markedly in advance of anything else available. But at the moment little is being done, beyond steady improvement by the established companies and sporadic effort by numerous design teams with inadequate resources. It is a *sine qua non* to suggest a real need for a completely new family of engines in the 50/150 h.p. bracket—when has it not been?—but this is one field in which the rate of technical progress is tempered by a host of retarding factors.

Small Helicopters

In contrast to the light plane field, that of small helicopters is dynamic and progressive, since such vehicles are in their infancy and are sought after by the military services. As a result a reasonable injection of money is being made which supports programmes devoted to the improvement of their propulsion systems.

Ten years ago it appeared that tip drive could form a relatively inexpensive and attractive means of propulsion for a small (i.e., under 30ft) rotor, particularly where flight-duration and noise requirements were not severe. Today it is generally felt that tip-drive systems are at their best only in the extreme sizes of very small or very large; and even then the number of attractive schemes is not greater than two.

Assuming that the bulk of small helicopters will have hub drive, the source of shaft-power must be of maximum power/weight ratio, have excellent reliability and be competitive in fuel consumption. General Electric have tended to put the cat among the pigeons by producing, in the T58, a turboshaft engine rated at an initial power of 1,000 h.p., weighing but 275 lb without primary reduction gear and with a specific fuel consumption better than 0.65. Many have argued that the T58, while attractive in a brochure, is in fact too complex and expensive, and that a less sophisticated piece of machinery is a better answer. Neverthless, the engine serves as an object-lesson in what can already be done, and the increase in performance which such a powerplant can make possible—even if installed in a helicopter originally designed for a piston engine—is very great.

For example, consider a helicopter designed to be powered by a 300 h.p. piston engine with an installed weight of 700 lb. It may be that, at full load on a standard day, 285 h.p. is required to hover, leaving 15 h.p. available for vertical climb. Conversion to the T58 should, in theory, make available 1,000 h.p., and the increased weight of the transmission and rotor system capable of absorbing such power should be less than the weight saved by the change in powerplant. Thus, so the mathematics suggest, the power available for vertical climb is increased from 15 to 715 b.h.p., and the rate of climb *pro rata*. With the original engine, no amount of supercharging, water injection and other boost systems could effect more than a quarter as great an improvement; and in a helicopter it is highly desirable to strip and simplify, not to add boost systems. Thus the modern turboshaft engine has come as a welcome shot in the arm, particularly to the several constructors of helicopters which are poor performers in tropical or high-altitude conditions.

Cost is by no means an insignificant factor. It is difficult to make fair assessments of cost between dissimilar engine types, but the modern 1,000 h.p. shaft-turbines appear to be likely to be priced at less than £20 per horsepower, complete with all accessories, when in full production. This is more than twice as expensive as the last batches of piston engines in the same power-class, but the latter are the legatees of decades of development and volume sales, and are right down at the bottom of the learning curve. In any case, the greater capital cost of the gas turbine is certainly proving no deterrent to its introduction, and within five years should be largely offset by reduced overhaul costs and increased component life. It is significant that, apart from the progressive development of the evergreen Bell 47 and Hiller 12 families, no major manufacturer is planning to build another helicopter with a piston engine.

Small one-man helicopters are currently under development powered by piston engines, pressure jets, ramjets, pulsejets, turboshaft engines and rockets. All the present evidence tends to rule out the tip-mounted rocket and pulsejet and, to a lesser extent, the ramjet (although the Dutch Kolibrie is a highly developed machine in the latter category). Piston engines hold the fort at present, although turboshaft engines are beginning to penetrate this field, the outstanding example being the Solar T62/T66 series, which should sell for under £2,000 and give 50 to 70 h.p., according to air temperature, for a weight of 50 lb. Piston engines are much heavier, although their availability and low first cost will not be surpassed for some years. The pressure-jet system may well prove to be the most attractive solution of all. In Yorkshire a firm of pneumatic-tool engineers have started the development of a 25ft rotor system in which pressure jets at the blade tips are fed with air from a hub-mounted centrifugal compressor which is turned, through step-up gears, by the rotor itself. The energy input to keep the system going is provided by burning fuel in the tip nozzles. A production price of under £600 is hoped for, and there seems to be no reason why this should not be achieved.

Transports

Aircraft designed for carrying payloads in remote regions—the Tundra, the desert, the jungle, and the Bush—have to compete with ox-carts and native feet, and their propulsion is dictated by the necessity of making the entire transportation system reliable, cheap to buy and to operate and capable of being efficiently maintained without introducing a host of new fuels, lubricants, tools, spare parts and skilled personnel. At present this virtually means piston engines; but the Rolls-Royce Dart has surprised many—especially those who have built piston-engined bush transports—and is already leading the gas turbine into remote areas.

On the main-line scheduled routes the edge of competition is razor-sharp, and its relentless pressure has; especially during the past five years, engendered a headlong quality-race in which operating equipment is depreciated over five to seven years and ruthlessly replaced by the offspring of a new generation. The business is fabulously expensive, and viewed dispassionately seems to serve the world's inhabitants (all potential customers at the airline ticket desks) very ill indeed. But already it has had a profound effect on the associated engine market; today there is not a single piston-engined aeroplane being built in the non-communist world for trunk-route operation. Even in the Soviet Union, where Aeroflot's internal routes are not subject to any competition at all, no big airliner with piston engines remains in production.

Ten years ago it was fashionable to present learned papers outlining the propulsive requirements of future transport aircraft, and it was almost a *sine qua non* for the author of such works to go to great lengths in comparing the simple piston engine, the compound diesel, the turboprop and the turbojet. Five years ago the picture had begun to resolve itself: all piston engines were consigned to the limbo of history and the proponents of the turbojet and turboprop were heatedly arguing about fare differentials, economics and passenger appeal. Today one is increasingly driven to the conclusion that there is no conflict at all. In the present airline environment the best engine for the future is the high-ratio by-pass turbojet, or fan engine, which in another ten years may dominate the trunk routes as completely as did the piston engine a decade ago.

Owing to the several variables involved, these engines can assume several forms. Rolls-Royce and Pratt & Whitney have chosen what is perhaps the preferred basic configuration, in which a few stages of fan blades, or an oversize low-pressure compressor,

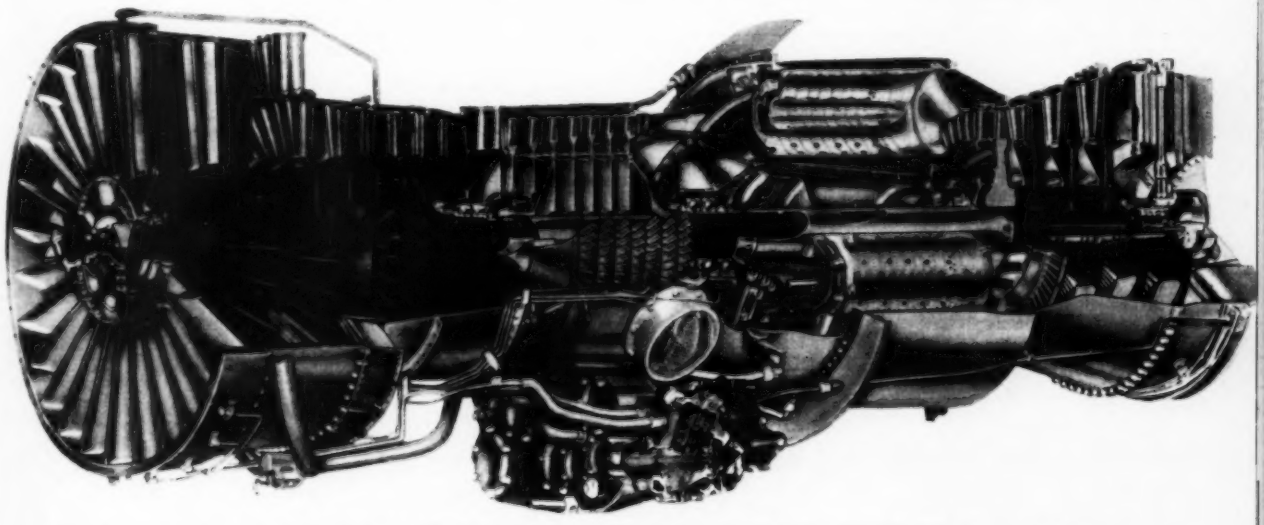
is driven by a mechanically independent low-pressure turbine (there are reasons why a single-shaft engine with front fan is undesirable). G.E. have produced an aft-fan engine by adding, behind the original turbine, a complete wheel with an inner ring of turbine blades and an outer ring of fan blades, the latter being carried on the tip-shroud platforms of the former. This raises severe structural and aerodynamic design problems, but has the advantage of requiring very little modification to the basic gas-producer (and thus is attractive as a retroactive modification).

Even the front-fan configuration can be applied in more than one way. Pratt & Whitney, below, have chosen to discharge the fan air overboard through propulsive nozzles on either side of the engine immediately behind the fan. Rolls-Royce have always carried it round to the rear in a by-pass duct, so that the hot and cold streams can be mixed in a single final nozzle. This can result in a theoretical improvement in specific consumption, and it also permits a thrust-reverser to be fitted. The American arrangement reduces engine weight, although this advantage is probably confined to the uninstalled engine.

This leads to an underlining of the fact that—as in the case with all engines—the only performance that matters is installed performance. Brochuremanship can be excellently served by quoting the figures obtained with a bare engine on the bed, but the aircraft-builder, or operator, needs to know what the engine will really do when it is hung in the airframe, coupled up to accessories taking 200 s.h.p., bled of air to de-ice the wings and intakes and to drive cabin turbo-compressors, and—perhaps the most important aspect of all—creating its own installed drag. In the latter connection, momentum drag is particularly worthy of careful study, theoretical gain in specific fuel consumption of up to four per cent. This, of course, does not apply to engines in which such mixing does not take place.

Of these factors, that of turbine-inlet temperature is the most intractable. The higher the by-pass ratio, the hotter should the engine be, and both the established turboprops—which have a very high theoretical by-pass ratio—and the fan units are unremitting in their demands upon the technology of blade materials. The problem is felt most keenly in the cruising regime, and cruise power has to be strictly limited to that at which turbine temperature, and hence rate of creep, are appropriate to the achievement of a comfortable blade life. Much is being learned by the operation of air-cooled turbine blades, and in this field Rolls-Royce appear to have a commanding lead. In fact, from the meagre evidence available—precise details are classified on military grounds—it may well be that such blading is not at present amenable to mass-production in the American manner, and that the high skilled-labour content could make it a very expensive business at over $2.50 per man-hour. The obvious alternative is to employ a better material, but the law of diminishing returns is putting a brake on progress in this direction. The latest creep-resistant alloys in use are already causing furrowed brows in the blade-fabricating shops; where only 10 deg C separate the "fluid" from the "unforgeable" states, there is barely time for one quick smack with a press before the piece has to be returned to the furnace.

In consequence, a very great deal will have to be done before air-cooled blades capable of making fan engines really worth while can be manufactured on a large scale and at an economic



A manufacturer's drawing of the Pratt & Whitney JT3D-1 turbofan. A direct development of the JT3/J57 two-spool turbojet, the JT3D incorporates two of the compressor stages from the big J91 nuclear turbojet (now defunct) which replace the first three stages of the existing low-pressure compressor. To supply the increased shaft-power required, the low-pressure shaft has been strengthened and modifications made to the low-pressure turbine, the first stage being enlarged and an additional second stage being added

since a large-diameter fan engine with a bench-rating of, say, 15,000 lb, may actually impart a net propulsive force on the aircraft at 100 kt during take-off of barely 13,000 lb.

Regarding the internal design of the engine itself, certain conclusions may be drawn merely by studying the fundamental performance curves common to all gas turbines. Unlike the simple turbojet, or the low ratio by-pass engine—but like the turboprop—the optimum transport unit achieves its best propulsive efficiency with an exceedingly high flame temperature. This renders the achievement of hot parts with acceptable commercial life (say 5,000 hr minimum) no easy task, and implies the adoption of air-cooled high-pressure turbine rotor blades in an advanced creep-resistant material. By the same token, it is more than ever necessary to obtain high-intensity combustion with minimum pressure drop.

Another fundamental factor is the choice of by-pass ratio, and the choice of low-pressure and high-pressure ratios (a ratio of ratios), which combine to determine the manner in which the aggregate propulsive thrust is shared between the cool fan air and the hot central core. Where there is wide divergence between the mean energies of the two flows it is impossible to mix them without incurring appreciable losses, but approximate parity enables mixing to be efficient; moreover, the additional heat transfer from the hot jet to the cold surrounding flow can produce a price. It can certainly be suggested that an optimum engine cannot be produced merely by sticking a fan on the front of an existing turbojet, and still less by adding a fan at the back. This is not intended to be a partisan attack on Pratt and Whitney and G.E.; everybody wants to add a fan today, and the facts of life hit both sides of the ocean with equal severity.

Direct Lift

Already responsible for more curiously contrived heavier-than-air vehicles than anything else in history, the need for the generation of direct lift by engine thrust is now recognised by a host of military and commercial operators. It is almost an impossible task to assess the relative merits of the widely varying systems already suggested, unless a common requirement is postulated.

Such a requirement was investigated in recent years by Canadair, two of the engineers involved subsequently outlining the pros and cons in a C.A.I. paper (reprinted in full in the *Canadian Aeronautical Journal* for November last). The work was done under a study contract from the Defence Research Board, the mission involving the "carrying of an intermediate cargo load in a prescribed envelope, or an equivalent passenger load, over a prescribed short range, returning light without refuelling." The profile specified was 80 per cent at optimum altitude and sea level for the remainder (assumed to be in the target area). Canadair

investigated five machines: fixed wing, four turboprops, large flaps, deflected slipstream; four turboprops, tilting wing; fixed wing with tip-mounted, tilting ducted propellers; standard twin turboprop with fuselage-mounted jet lift; and an advanced configuration with lift/propulsive turbojets distributed along the rear portion of the wing, which could be hinged downwards.

Many of the results obtained from the thousands of calculations performed were astonishing, and serve to emphasize the folly of jumping to conclusions; for example, the fifth (all-jet) study proved to be the cheapest to operate on either a single- or a split-level mission. However, the basic conclusion of the study was that there was "real promise of satisfying the requirement" only with the first two configurations, and that of these the second (tilting wing) was superior. Turning to considerations of actual hardware, Bréguet have chosen the first layout (but have evolved a sophisticated and advanced vehicle), while Hiller have, to U.S. Navy contract, adapted a once-conventional logistic transport to the second—the optimum tilt-wing—configuration. When the Hiller X-18 starts flying its behaviour should be worthy of study.

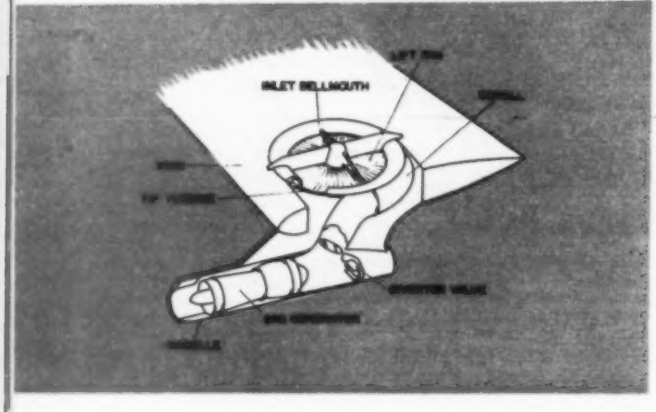
From the engine viewpoint the conclusions drawn are very acceptable. All that is needed is further development of turboprops of maximum power/weight ratio, together with large-diameter propellers of minimum weight and the associated reduction gearing and wing-tilting mechanisms. Nothing very arduous; yet it is in meeting just such straightforward requirements that an individual firm can beat its competitors. To an ever-increasing degree, success will go to companies whose basic approach is right, and will elude any company which fails to appreciate that, for example, the best engine for a tilt-wing machine may have to be developed from a clean sheet of paper.

There are, of course, many other types of aircraft in which direct lift is provided. One family which may well become of major importance is that which embraces the profusion of VTOL tactical combat aircraft which promise to spawn by the thousand. Discounting propeller-driven machines, such as the American XFV-1 and XFY-1, the first of this family actually to be built is the SNECMA C.450 Coléoptere. As is well known, this consists chiefly of a single turbojet around which is mounted an annular wing. After taking off from a tail-sitting attitude the C.450 is controlled during engine-supported flight by aerodynamic jet-deflection accomplished by injecting compressor-bleed air from selected inwards-facing slits around the engine propulsive nozzle. After transition to wing-supported flight, control is accomplished by aerodynamic surfaces carried around the wing.

There is much to be said for such a system, which appears in every way preferable to pivoting the powerplant. (The converse is true of large rocket motors, as is presently noted.) In a recent public lecture Dr. S. G. Hooker, of Bristol Siddeley Engines, confirmed his company's interest in such arrangements, saying [colloquially], "Our approach is to employ swivelling jets, not of the engine itself but the actual jet thrust flow." It has several times been suggested unofficially that an arrangement of this kind is to be the key to the Hawker P.1127, the third-generation attack aeroplane for NATO. Officially described merely as having a "special Bristol engine," it seems fairly clear that the P.1127 will be the first fixed-wing fighter capable of rising off the ground vertically in a normal flying attitude (it may be preceded by the Bell XF-109, for which a U.S.A.F. contract has already been let).

There are several methods by which the thrust axis could be varied to suit the different regimes of flight. All such systems are likely to be designed for optimum efficiency in the translational regime (either at cruising or at supersonic maximum speed) and so specific consumption in the hovering mode will be high—probably well over 1.5.

A suggested lifting/propulsion powerplant for a relatively high-speed fixed-wing VTOL aircraft by American G.E. Some comments on this arrangement are given at the top of column 2



Such an arrangement would therefore be unattractive for any vehicle intended for prolonged hovering. It is, however, quite possible to invent propulsion systems with even more varied characteristics, and a number are discussed in the paper *Convertible Turbojet Engines for VTOL Aircraft* by Messrs. Zipkin, Rossbach and Brown of American G.E. and read earlier this year. A typical such engine is shown below. Amongst the advantages claimed for such a powerplant are improved matching between cruise and lift thrust, thrust vectoring without engine or wing rotation, no limitations of flight speed, the considerable growth-potential consequent upon the use of interburning (combustion of additional fuel between the gas generator and the tip turbine) and the fact that existing gas generators may be used. To meet the engine-out case it is suggested that four such powerplants should be interconnected by cross-ducting.

Among a range of applications suggested, the authors of this paper cite the case of a projected observation aircraft, with a gross weight of 13,500 lb including a crew of two and 600 lb of electronics. Powered by two J85 engines, with a single fuselage-mounted lift fan, the aircraft could take off vertically, fly 200 n.m. at sea level, loiter for two hours, cruise back and land vertically; with zero loiter time the cruising range would be 700 n.m. The maximum speed would be 550 kt (M 0.83). This work follows upon earlier studies by G.E. which were summarized in this journal on February 1, 1957.

Ballistic Vehicles

It is appropriate to say a few words about the probable future propulsion of large ballistic missiles, and orbital or skip vehicles which are not intended to leave the neighbourhood of the earth.

At present there seems little doubt that for several years the most important propulsion systems in this field will continue to be large liquid-propellant rocket motors, using liquid oxygen as the oxidant. It is safe to assert that such powerplants will provide at least 95 per cent of the total impulse required. Rocketdyne's method of chamber construction—the basket-tube system, described in the section dealing with that company in the catalogue section of this issue—is likely to be widely adopted. It eliminates many manufacturing problems, facilitates the construction of chambers with Prandtl nozzles (an optimum divergent nozzle with a concave interior form) and results in an assembly of minimum weight. Vehicle control will invariably be accomplished by gimballing the chamber rather than by deflecting the jet with refractory vanes.

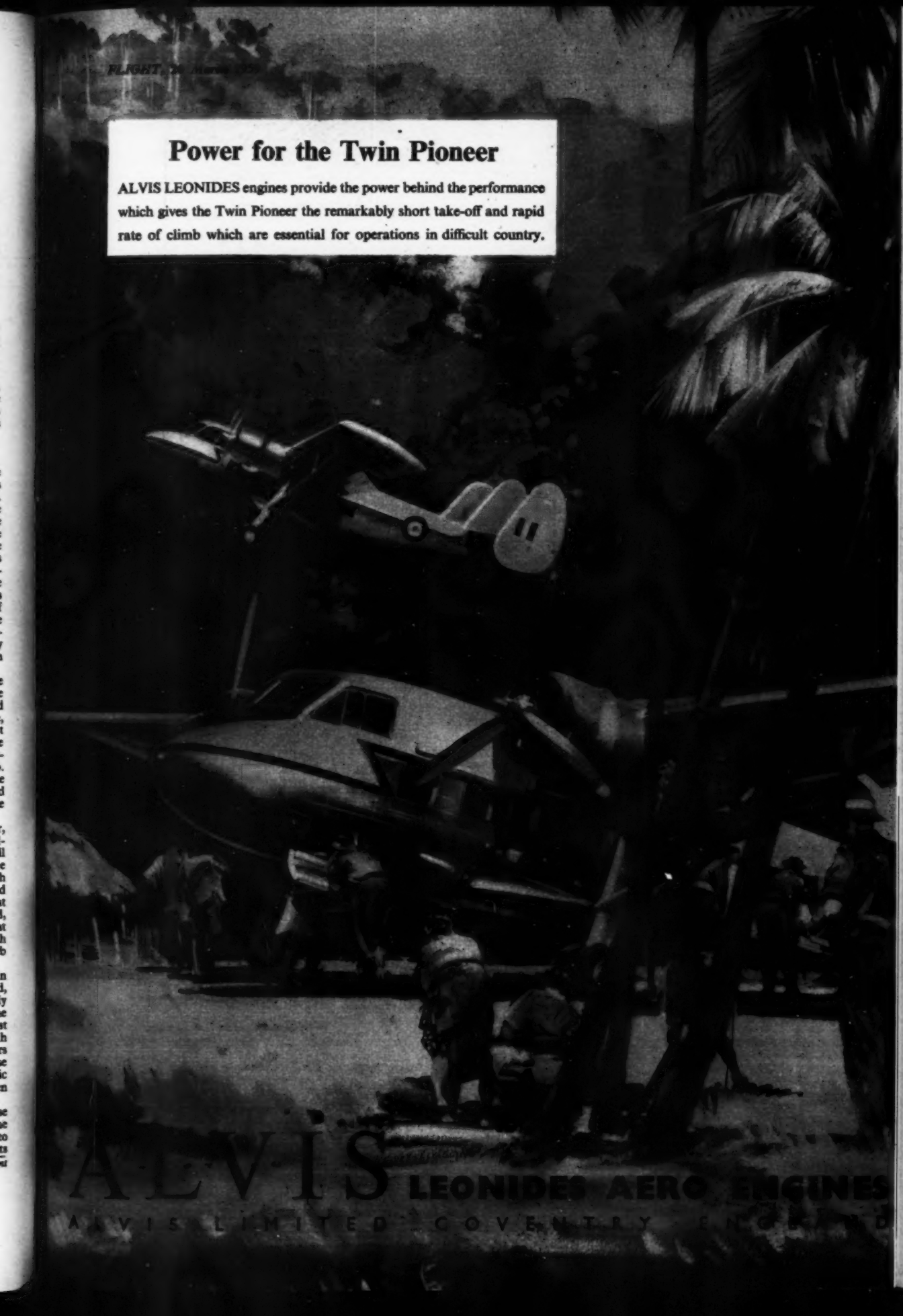
There is, of course, tremendous scope for development in the classic liquid-propellant-engine. Not only can units be made progressively smaller and lighter for a given rating but, provided immense financial and technical support can be made available, engines can be produced with much higher thrust than any yet attempted. As an initial, rather crude step, Rocketdyne are developing a cluster unit consisting of an octet of Thor/Jupiter-size chambers, uprated to give an aggregate thrust of 1,500,000 lb. This could place 10,000 lb in a stationary Earth orbit (22,400-mile radius) or land 2,000 lb gently on the Moon. Rocketdyne also hold a U.S.A.F. contract for a next-generation engine, with a single chamber rated at 1,000,000 lb growing to 1,500,000.

In a recent paper, T. F. Dixon, Rocketdyne's chief engineer, pointed out that development of such a huge unit will be a formidable task; "turbomachinery capable of the power outputs of small municipalities will be required to feed the propellants to the chamber, stable combustion chambers will have to be built with combustion densities many times that of existing engines, and plumbing, valves, and so forth, will be beyond the range of current experience." Nevertheless, giant rockets will be essential; and, to show that Rocketdyne look ahead, Mr. Dixon goes on to point out that a 20×10^6 lb engine could place 300,000 lb in a low Earth orbit, take 200,000 lb and land it on the Moon or orbit 60,000 lb round Mars and return it to the Earth.

Notwithstanding the great strides which continue to be made in the field of solid propellants—especially in the military field, where they are particularly attractive—it does not appear likely that they can be employed in high-performance vehicles where the achievement of maximum specific impulse* is all-important. Test firings are already taking place with fluorine, in conjunction with derivatives of amine (such as UDMH); other reactive oxidizers can achieve specific impulses theoretically higher than those attainable by any solids. Ultimately the highest chemical specific impulse should be achieved by engines running on liquid hydrogen and either liquid oxygen, liquid fluorine or liquid ozone.

On p. 385 it can be seen how low is the best specific impulse which can be achieved by any chemical rocket. When all the possible combinations are exhausted it will still be possible to take a major jump by discarding today's molecular propellants

**Specific impulse I is thrust obtained from a given rate of propellant consumption; if the units are lb and sec, I is measured in sec.*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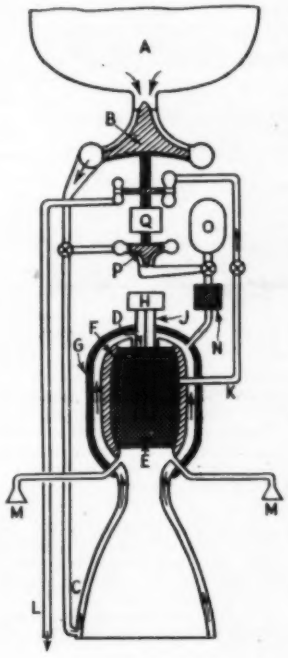
and employing free radicals. The latter are metastable atoms; molecular hyrodgen H_2 can be split into a pair of hydrogen radicals H, H, which upon recombination under controlled conditions can provide a propulsive jet with a specific impulse of 1,500. During the past five years the U.S. Department of Defense has spent fairly considerable sums on free-radical research, and laboratory rocket motors employing such violently reactive propellants are already in the hardware stage. The chief trouble, of course, lies in the difficulty of pouring free radicals into a tank, shutting the lid and then finding free radicals still in the tank when they are wanted. Atomic hydrogen is almost impossible to store, and can be frozen only at a temperature which closely approximates to absolute zero. Such propellants will not be widely employed for a decade at least, but may find application in the more advanced powerplants discussed under the next heading.

Outer Space

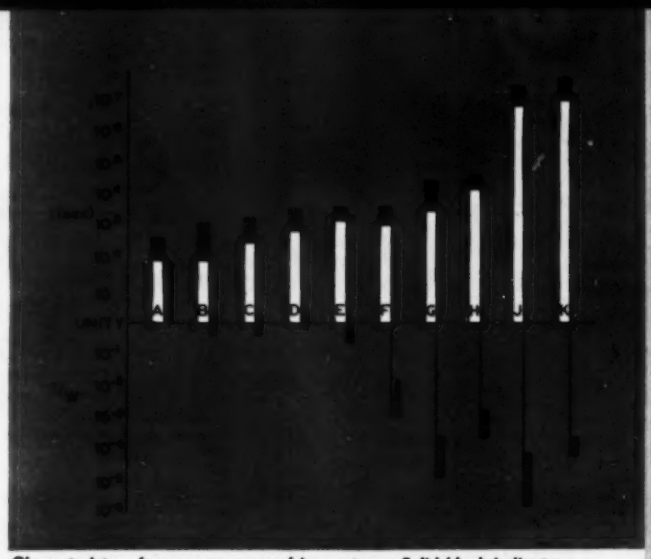
By definition, outer space is devoid of air, or any other substance—the word is used in the strict physical sense—which might be harnessed to form a propulsive jet. It therefore follows that any vehicle designed for navigating space must carry all the material for its propulsive jet along with it, unless one attempts to provide thrust and control forces by reflecting electro-magnetic (alpha or visible-light) particles or by mastering gravity itself.

Neither of the latter ideas is currently regarded as immediately feasible, and so recourse must be had either to a chemical rocket or any of a considerable variety of newer devices. Chemical rockets obtain thrust by the chemical combination, or combustion, of a fuel and oxidant, and all present-day operational rockets fall into this category. Already such power units have placed satellites in orbit around both the earth and the sun; but the conflicting factors of total impulse required (thrust multiplied by burning time) and gross weight make the conventional rocket unacceptably heavy where it is essential, for true space navigation, to provide thrust for steering purposes (admittedly only very small forces are needed) over a period which may extend over a number of years.



A schematic representation of some of the working parts of a nuclear rocket engine. The system shown is purely arbitrary and the closed-circuit link in the cooling system may not be proved advantageous in practice

Propulsion requirements for space flight are simply stated: the need is to provide thrust of a few pounds, or even ounces, over a very long period, without making use of any surrounding medium to support combustion or provide material from which a propulsive jet may be made. Within this broad framework tens of thousands of engineers in the U.S.A. and the Soviet Union—and, one imagines, in other countries—are searching for the best answers. Already much has been written and said, and the most difficult aspect of conducting a broad survey in everyday language is not to find out what is going on but to weigh up the relative merits of the many systems already under investigation.



Characteristcs of some space propulsion systems. Solid black indicates the range of specific impulse I and the shaded strips show the range of thrust/weight ratio. A, chemical rockets; B, nuclear rockets; C, plasma engines; D, free-radical rockets; E, direct fission engines; F, solar furnace systems; G, ion engines; H, thermonuclear rockets; J, photon sails; K, α-particle sails

Two of the most fundamental characteristics of possible space propulsion systems are given above. Bearing in mind that the ordinate is drawn to a logarithmic scale, the first fact that becomes apparent is that there is an enormous variation between, say, a chemical rocket and a "sail engine." The latter would, for a given thrust, weigh about 20,000 times as much as the former; in fact, since the chemical rocket would probably be designed to produce perhaps 1,000 tons of thrust to provide boost-propulsion for leaving the earth, while the sail would generate maybe half an ounce, it is pointless to attempt a direct comparison. What is obvious, however, is that there are going to be propulsion systems available with widely differing characteristics well matched to the widely different requirements of the several portions of any future space mission.

Chemical rockets. Little need be said here, since it is highly doubtful that such powerplants will ever be employed in genuine outer-space flight. They are, however, well suited to the initial boost propulsion of spacecraft, and may well retain this rôle indefinitely.

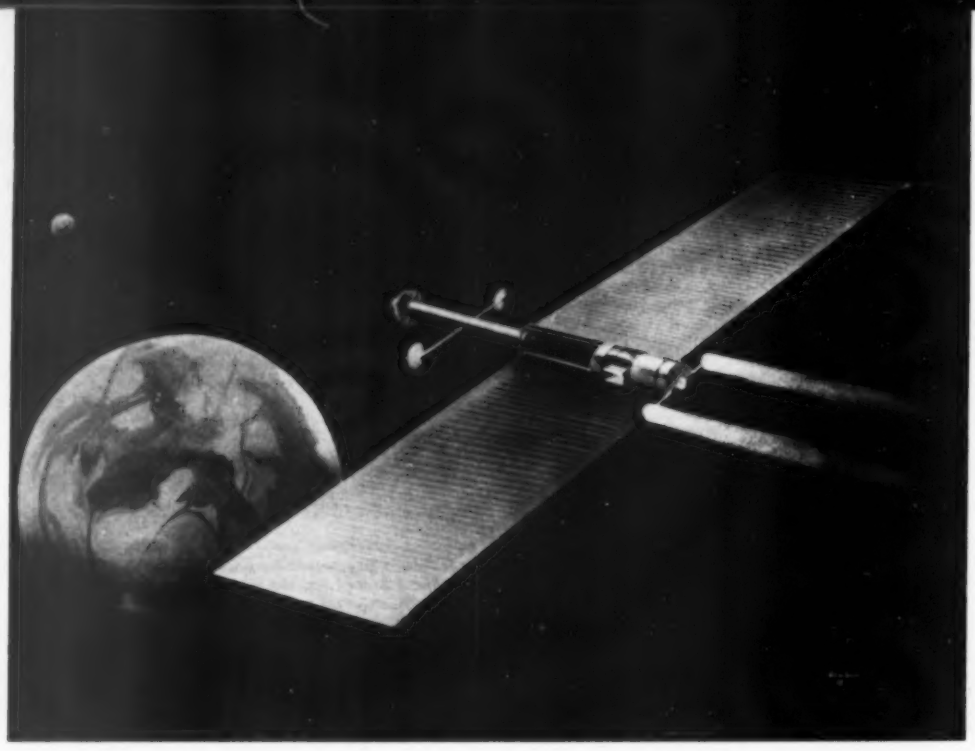
Nuclear (fission) rockets. As already noted, one of the most important parameters in any jet-propulsion system is specific impulse; and this is largely dependent upon the velocity of the jet. The higher the jet velocity, the greater the specific impulse, and—other things being equal—the better will be the system efficiency.

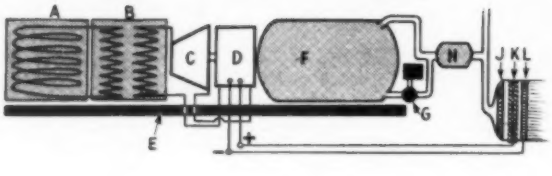
Jet velocity is in turn a function of chamber pressure, combustion temperature, nozzle design, expansion ratio and, above all, the density of the substance of which the jet is made. For minimum density it is desirable to select a material of very low molecular weight. If a means could be found to feed a working fluid into the combustion chamber and heat it without the need for chemical reaction (i.e., combustion) to take place, then it would at once become possible to use a pure gas, such as hydrogen, instead of a mixture of products from the combustion of hydrocarbon fuel and oxygen. Such a step would reduce the atomic weight and density of the jet by at least one order of magnitude, and raise the theoretical maximum specific impulse from 350-400 to something in excess of 1,000.

The obvious way in which a low-density working fluid could be heated without itself becoming mixed with heavier material is to pass it through a nuclear reactor. The controlled fission of a nuclear fuel, such as U_{235}, generates heat which can be imparted either directly, by passing the working fluid straight through the reactor, or indirectly, by employing two heat exchangers and a closed-circuit primary cycle. The former is the logical arrangement for a nuclear rocket.

A schematic nuclear-fission rocket is sketched on the left. It is at once evident that, geometrically, such a unit need not differ too greatly from a chemical rocket; but the actual design and production of a worthwhile nuclear rocket engine is a herculean task. Last year Col. Jack Armstrong, of the U.S.A.F. and Atomic Energy Commission, told the American journal *Nucleonics* that it would take at least a year to arrive at a decision as to what sort of unit should be built, and that hardware is ten years away. Rocketdyne, one of the chief companies working in the field, place the date of entry to service of a nuclear rocket around 1975.

For the record, there are four current American programmes: Rover nuclear rocket (Los Alamos Scientific Laboratory), Pluto nuclear ramjet (Livermore Radiation Laboratory), Snap (Satellite





A Nuclear reactor
B Sodium heat exchanger
C Mercury-cooled turbine
D D.C. generator
E Mercury radiator
F Cesium tank
G Turbopump
H Vaporizing chamber
J Injection plate
K Positive ionizing grids
L Negative grid

Above is an impression by a Rocketdyne artist of the "Snooper" vehicle, driven by an ionic engine, in which the jets are composed of charged particles. The suggested principle of operation is shown on the right; the radiator E appears as a pair of large wing-like surfaces in the illustration above. In the key diagram only one of the particle accelerators is shown

AERO ENGINES 1959 . . .

Nuclear Auxiliary Powerplant) and an ionic system (discussed later). Rover and Pluto have made fair progress; hundreds of companies, including Rocketdyne, Aerojet, Curtiss-Wright, Marquardt, Atomics International and the Erco Division of ACF Industries, are churning out hardware—but all of it is purely experimental, and bears little resemblance to pieces of a flyable system.

It is not difficult to appreciate why this is so. In the industrial nuclear field of the so-called Western world, it is the full-time task of some 50,000 engineers to effect improvements of some two or three per cent in the basic parameters of thermal reactors. The nuclear rocket demands improvements of many thousand per cent. For example, Calder Hall—although admittedly "agricultural machinery" in the same sense as is the Rolls-Royce Dart—sets a fair standard in putting out 92MW thermal from a reactor core in the form of a cylinder 21ft high and 31ft in diameter, weighing 1,200 tons. A spacecraft nuclear rocket, using hydrogen as the working fluid, with a thrust of from 400,000 to 3,000,000 lb and an I of 750 sec would, to be of any use at all, have to put out from 5,000 to 50,000MW thermal from a core not larger than about 6ft in any direction.

The key to such performance lies, of course, in running the core at a temperature roughly ten times as great as in the present reactors. It is, perhaps, not immediately evident that such a temperature is far beyond the capacity of any known material. And there are equally great problems to be faced in the fields of gamma heating, pressure-chamber and fuel-element design, reactor control and a host of similar parameters.

Assuming, for the moment, that such objections can be overcome, the rocket would work quite simply. The working fluid—hydrogen, helium or fluorine—is stored in liquified form in an insulated tank. It is fed by turbopump at some 1,500 lb/sq in to a regenerative cooling jacket around the chamber, and then through the reactor core. In a small fraction of a second it is converted to hot gas, at around 2,400 deg K, and leaves through the propulsive con-di nozzle. A bleed pipe extracts gas at a lower temperature, and at a pressure of 300-600 lb/sq in, to provide the working fluid for the turbopump, the exhaust from which is dumped overboard from a separate pipe with a propulsive nozzle. Altogether, the nuclear rocket should be comparable in size with chemical engines of the same thrust. As an engine alone it will be much heavier; but on a basis of engines-plus-fuel it will be lighter, and much more efficient, for extended space voyages involving appreciable actual running time—perhaps 15-25 mins—not necessarily all in one unbroken period.

Nevertheless, all rocket units of conventional form are subject to unalterable limitations which restrict the maximum theoretical performance. Chemical rockets cannot burn hot enough, nor produce a jet of sufficiently low molecular weight. Nuclear rockets are better on both counts, but the full potential temperature which can be realized by fission, and which would give tremendous jet velocity and specific impulse, is far too high for any conceivable structure. There is no hope of ever obtaining sufficiently good materials; the strength of the inter-molecular bond is a clear-cut fundamental limitation. For the final step towards a perfect space engine the jet must be kept remote from any part of either the powerplant or the vehicle. This can theoretically be achieved by several systems, some of which are, on paper, quite simple.

One method of approach, stemming directly from the solid-core reactor rocket, is the gaseous-core rocket. In this the fissile material is present in gaseous form, and the gas which forms the jet is actually mixed with it inside the reactor shell. Heat transfer takes place directly, gas-to-gas, the reactor walls remaining relatively cool. Provided that the expansion can take place through a suitable nozzle, there is no barrier to the achievement of jet temperatures several thousand degrees higher than any currently permissible. A severe disadvantage is that fissile material is almost certain to be carried away in the jet, so that the fuel consumption will be higher than that required by the heat output.

Thermonuclear fusion rockets. It may be that in twenty, or even ten, years the fission process will be regarded as archaic. It can take place only if a super-critical mass of expensive, and relatively scarce, fissile fuel is burnt in a costly and heavy reactor to yield dangerous and wholly unwanted waste products. There are secondary drawbacks, such as the need to design surrounding structures and systems to withstand irradiation. Controlled thermonuclear fusion largely overcomes these problems at one stroke, and opens the way to a vast increase in operating tempera-

ture (and hence in the specific impulse of a propulsive jet).

In fact, so attractive is the principle of controlled fusion, the entire world programmes of research into the optimum types of powerplant for spacecraft (and in many other fields) have been thrown into the melting pot. Only a year ago these programmes were orderly; they envisaged steady work on ion engines, plasma jets, particle accelerators and solar sails (of which more anon), while the idea of controlled fusion—in other words, a tame H-bomb—was justifiably regarded as "a long way down the road." Today recent advances in the art of magnetohydrodynamics indicate that controlled thermonuclear reactions are only just around the next corner; in fact, such a reaction may already have been achieved, although without producing net power. The question of which horse to back has become almost unanswerable, and a wrong choice means billions of dollars, pounds or roubles, and the loss of valuable years.

It is perhaps appropriate to look at some fusion engines first. In general they all conform to the pattern of using a plasma as the working fluid and containing it within a strong magnetic field.

Plasma is, in this connection, the name given to an ionized gas. A gas becomes ionized when, as a result of absorbing sufficient energy, its molecules split up into free electrons (negatively charged) and a positive remainder (protons, neutrons and any remaining electrons). The positively charged ions and the free electrons naturally respond to any superimposed electric or magnetic field, and the gas therefore becomes both electrically conductive and capable of being constrained by magnetic means. Plasma thus forms an ideal medium for the generation of a propulsive jet of low density and immense temperature, up to around 100,000,000 deg K.

At present the most optimistic raw material to use—since it is abundantly available in the oceans, and its fusion reaction is sustained at the lowest temperature—is deuterium, the hydrogen isotope of atomic mass 2 which is freed by the electrolysis of heavy water (for about $20 per pound). The gas is injected into a toroidal or cylindrical chamber and is ionized by being subjected to exceedingly powerful shock waves, or other means, which cause sufficient compression and temperature-rise for free electrons to be produced at the ionization level, thus converting the gas to a conducting plasma. Then, by a combination of pinching and stabilizing magnetic fields, and a field created by axial current passing through the plasma itself, the thermonuclear reactions $D+D=T+p+4MeV$ and $D+D=He_3+n+3.2MeV$ to take place.* The tremendous heat output then has to be converted as efficiently as possible to kinetic energy by a magnetic-field nozzle. Some 3 per cent of the power will be absorbed as radiant energy by the reaction chamber and surrounding structure, and it is suggested that this energy should be carried away by injecting lithium (a light alkali metal) through cooling ports in the chamber, from which it would swirl into the plasma and be ejected in the propulsive jet.

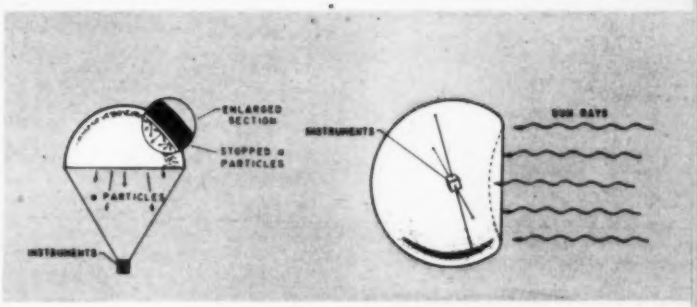
Plasma can, of course, be created and manipulated without thermonuclear fusion, and an electric arc is probably the most straightforward means of doing so. Starting with either a liquid or a gas, it is possible to hold stable temperatures of around 100,000 deg K, and specific impulses from 600 to about 1,500 have been obtained in the laboratory.

These plasma rockets can, with suitable design, achieve thrusts of thousands of pounds; it is possible to describe on paper a fusion engine, with gas-injection, capable of lifting itself and an associated vehicle off the Earth. However, as already noted, launching can best be done by big chemical rockets. In outer space gravity falls off to very low values and it then becomes possible to propel and steer big vehicles with jets developing aggregate thrusts of perhaps one-hundredth of an ounce.

Space propulsion. One quite attractive low-thrust system is the ion, or ionic, rocket. Ions, being approximately of the mass of an atom, and influenced by electric fields, can be accelerated very rapidly by electrostatic means. For example, project "Snooper" (above left) utilizes cesium ions, produced by heating cesium vapour in platinum grids; the ion beam is then carefully directed and expelled. With an accelerating charge of 12 kV the jet velocity should reach 500,000ft/sec, giving an I of around 15,000 sec. An even simpler plasma jet can be made merely by discharging a heavy current across a pair of consumable electrodes containing, for example, deuterium ions. The latter can be discharged as a succession of doughnut-shaped plasmoids, which are accelerated by the electro-magnetic field to about 100,000ft/sec. A Russian scheme uses a piece of fine wire joining the electrodes, the wire being vaporized by the discharge of a large capacitance.

Unfortunately, these charged-particle devices consist of two parts. One part is the "combustion chamber," perhaps small enough to be carried in a suitcase. The other part is a means of supplying electrical power of many megawatts; and we have yet to devise a means for placing a giant power station like High Marnham in orbit, let alone in outer space. Nuclear energy is the obvious source to investigate, and the fusion system already described may well prove capable of generating its own current. Any engine which cannot sustain itself electrically may well have to be discarded. Snooper, for example, is shown complete with a nuclear generating set, and Project Snap, referred to earlier, is a programme aimed at producing such a unit.

*Deuterium, tritium, proton, mega-electron-volts, helium 3 and neutron.



These sketches stem from the N.A.C.A. (now N.A.S.A.) and depict an alpha-particle sail and a photon sail. Figures for the former include: weight (thickness 0.0012in), 0.009 lb/sq ft; thrust, 10^{-6} lb/sq ft; t/w (ideal), 10^{-4}. Corresponding figures for the latter (t=0.0005in) are: 0.003 lb/sq ft; 2 x 10^{-7} lb/sq ft; and 7 x 10^{-5}

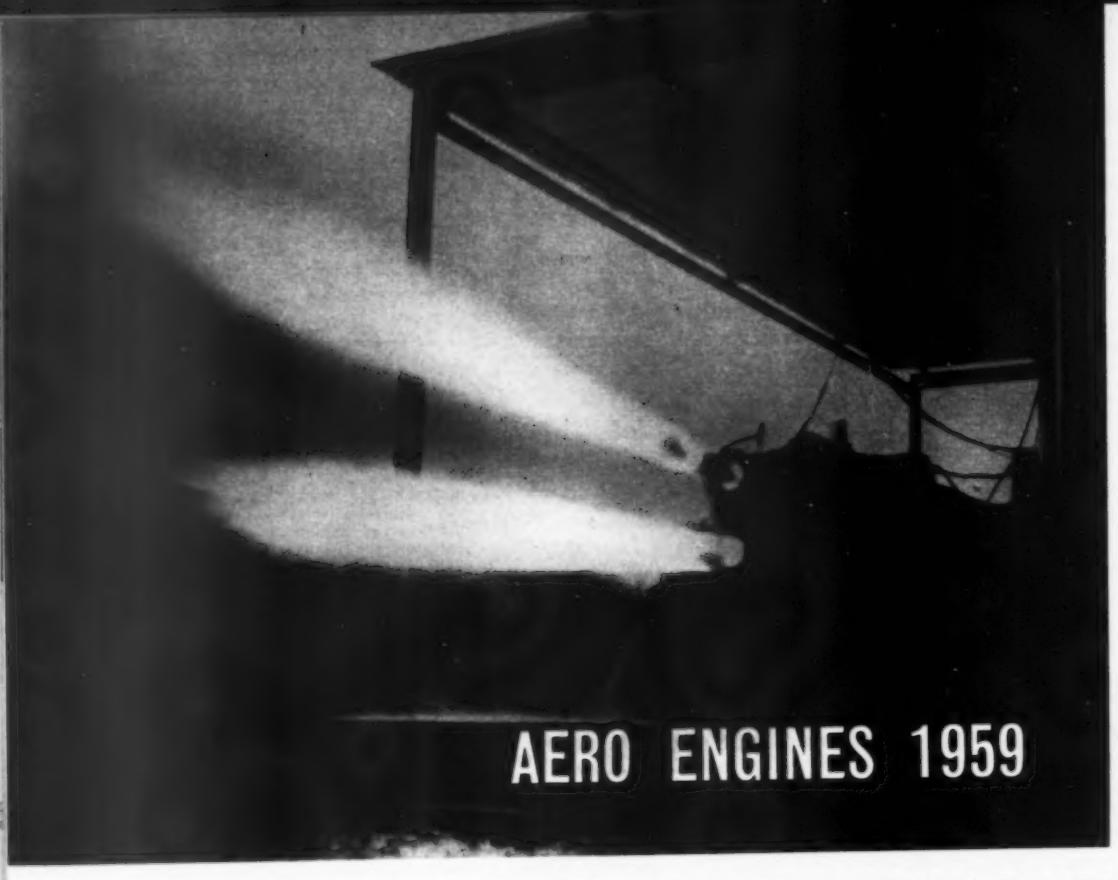
Bearing in mind that electric power is produced whenever a conductor—such as a column of ionized gas—moves through an electro-magnetic field, it would seem possible to do the job without having recourse to such pedestrian and earthbound devices as heat exchangers and turbo-generators.

This review cannot close without noting that man has always learnt to live off his environment, and to achieve flight propulsion by utilizing any convenient surrounding energy (such as oxygen). Space is full of energy, in a variety of forms, many still imperfectly understood. Solar energy is quite intense when undiluted by terrestrial smog, and can be used to provide heat to form a propulsive jet from liquid hydrogen, or to ionize cesium vapour to form ions (below); it can even be used directly, the vehicle being equipped with a vast sail giving thrust by utilizing the photon energy of the sun's light (above). The last arrangement does not seem practicable, neither does the other system illustrated above, in which the thrust is produced by alpha particles.

But one must not be discouraged by the prospect of a theoretical maximum thrust perhaps one-millionth as great as that which can today be generated by a chemically fuelled engine of the same size and weight. These sail engines, like the ships of old, could roam the great sea of space for ever; a vehicle, in fact, for a modern Ancient Mariner, with a stellar-monitored inertial navigation system.

W. T. G.

Below is yet another idea which is at present little more than a pretty picture. This vehicle has a solar furnace, and it may well be that the best arrangement would be to use the heat to generate jets of uncharged cesium ions. Two such jets can be seen emanating from the rear



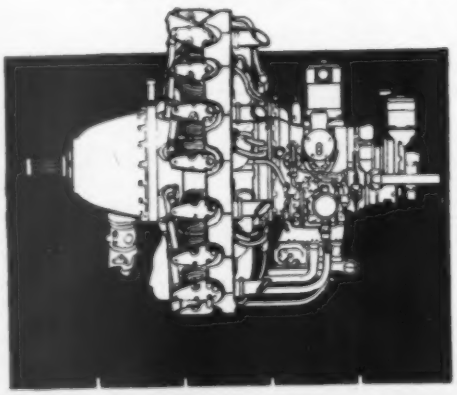
AERO ENGINES 1959

COMPILED BY THE TECHNICAL EDITOR

THE words "aero engine" conjure up a picture of something massively weighty, with cast casings held together by rows of bolts, and an overall shape and size with which we are familiar. But the term must soon include rocket engines with chambers large enough to swallow an average room, yet fabricated from relatively thin sheet; and, at a later date, even stranger devices such as those described on the previous page. It is therefore becoming increasingly difficult for a reviewer to know where to leave off. In this, the writer's fourth consecutive review of the world's aero engines, liquid-propellant propulsion systems for large ballistic missiles are included, but solid rockets are not; in any case, engines for conventional air-supported aircraft make up over 95 per cent of the total. The drawings have each been prepared against a solid black panel with a scale of five feet marked along one edge; and at the end of many of the written descriptions will be found references to relevant articles previously published by this journal.

GREAT BRITAIN

ALVIS *Alvis Ltd., Coventry.* In the aeronautical field this company have for 21 years been engaged in the development and production of a family of air-cooled radial piston engines using a cylinder with a bore of 4.8in. and a stroke of 4.41in. The greater part of the effort has been devoted to a single-row, nine-cylinder engine named the Leonides. This is described below, together with the two-row, 14-cylinder Leonides Major. Development of both is being actively continued for numerous aircraft and helicopters, and the company are looking keenly at the prospect of re-engining a substantial number of existing aircraft at present fitted with relatively worn out Wasp Juniors, Wasps and similar powerplants.



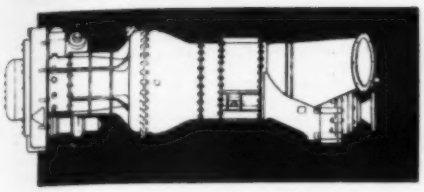
Alvis Leonides 531 Military and commercial piston engine. Nine air-cooled, poppet-valve cylinders, supercharger of 6.5:1 ratio and reduction gear of 0.625 or 0.5:1 ratio. Bore and stroke both 4.8in; swept volume, 783 cu in; dry weight, 860 lb; max rating, 650 h.p. at 3,200 r.p.m. with 8 lb/sq in boost at 2,000ft, with consumption of 468-500 lb/hr; max cont. rating, 585 h.p. at 3,000 r.p.m. with 6.5 lb/sq in boost at 2,500ft, with consumption of 392-418 lb/hr.

Leonides When it was designed in 1938, this neat radial was intended to produce 450 h.p. at sea level for take-off purposes, and to have a maximum continuous rating of 400 h.p. (at which rating it was type-tested in the same year). Progressive development has resulted in the engine in its most recently type-tested form producing 580 h.p. for take-off and 495 h.p. continuously. This increase in performance has been made possible by raising the boost pressure and by design changes which have also substantially improved the overhaul life. Engine r.p.m. have remained unchanged and the swept volume has not been altered.

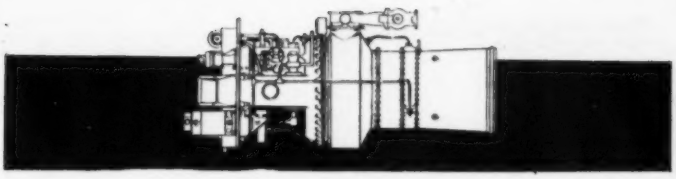
A typical version for fixed-wing aircraft is the Leonides 510, fitted to the Scottish Aviation Twin Pioneer and Hunting President. Geared and supercharged, this variant is designed to operate on 100 octane fuel (a lower grade can be used by the incorporation of minor modifications), weighs 795 lb and has a maximum rated power of 570 h.p. at 3,000 r.p.m. with a boost pressure of 8 lb/sq in. Equipment includes a Hobson fuel-injection system feeding into the eye of the supercharger, together with either an electric or cartridge starter. For helicopters the vertically mounted 524/1 can be taken as typical; with a net dry weight of 730 lb this unit has a 5-min sea-level rating of 505/525 h.p. at 3,000 r.p.m. with 8 lb/sq in boost, and a one-hour rating of 465 h.p.

Having regard to requests from aircraft manufacturers for greater power and increased maximum-power altitudes, Alvis have evolved a developed Leonides which, although installationally virtually interchangeable with earlier engines, has appreciably greater swept volume (raised from 718.6 cu in to 783 cu in). This increased capacity has been obtained by increasing the stroke to 4.8in, thus making the engine "square"; at the same time the internal power section of the carcase has been strengthened, and these changes have resulted in an increase in diameter from 41.5in to 43in. Full data for a fixed-wing version of the new series 530 engine are given beneath the drawing. Normal category approval of the 531 was obtained on February 12 of this year. At the beginning of this month the long-stroke Leonides had been subjected to approximately 1,500 hr bench running, and a pair of engines had each completed over 50 hr flying time in a Scottish Aviation Twin Pioneer. A helicopter version is being made available, with generally similar power ratings.

Leonides Major Using the same size of cylinder as the original "over-square" Leonides,



Blackburn A.129 Mk 3 Company-sponsored turboshaft engine. Compressor with two axial stages followed by single centrifugal stage, annular combustion chamber with fuel injection from rotary spray, two-stage compressor turbine and single-stage power turbine. Max installational diameter, excluding exhaust duct, 20.062in; intake diameter, 14.625in; overall length as depicted, 62.66in; dry weight, including fuel, oil and ignition systems, reduction gearbox and bifurcated exhaust duct, 390 lb; max rating, sea level, static, i.s.a., 968 s.h.p. + 93 lb thrust at 35,000 compressor r.p.m. and 30,000 power-turbine r.p.m. with s.f.c. of 0.681 lb/hr/s.h.p.; max cont. rating, same conditions, 815 s.h.p. + 82 lb at 34,000/28,100 r.p.m. with s.f.c. of 0.718.



Blackburn Palouste 805 Military air-compressing gas turbine. Single centrifugal compressor, annular combustion chamber with rotating fuel-injection nozzles, and single-stage turbine. Max diameter, 17.7in; height, about 18in; length, basic engine, 28.62in; dry weight, 178 lb; delivery 2.725 lb/sec air at 41.55 lb/sq in gauge, with fuel-flow 310 lb/hr.

the Major is a 14-cylinder, two-row engine with an overall diameter of only 38.925in. The fixed-wing Mk 702 has a maximum rating of 885 h.p. at 3,000 r.p.m. with 9.25 lb/sq in boost at a height of 1,500ft and with an s.f.c. of 0.72 to 0.755 lb/hr/h.p.; the Mk 155 helicopter engine it fitted to a large number of Whirlwind HAR.5 and HAS.7 helicopters of the Royal Navy, Whirlwind Mk 8s of the Queen's Flight and S-55 series II machines of the Austrian Air Force. Weighing 1,110 lb, this engine has a 1 hr rating of 805 h.p. at 2,900 r.p.m. with 6.5 lb/sq in boost at 2,750ft.

BLACKBURN *The Engine Division, Blackburn & General Aircraft Ltd., Brough, Yorkshire.* Small numbers of piston engines are still being manufactured by Blackburn, the Cirrus Major III being produced for the Hindustan HT-2 and the Bombardier 208 remaining in limited production for the Auster AOP.9. Practically all the engine division's work is now centred on small gas turbines developed at Brough from the original designs by the French Turboméca company.

Artouste A 475 s.h.p. single-shaft engine, the Artouste has a front reduction gear and is employed in a number of airborne applications to provide shaft power, compressed air and electrical loads. Sponsored by the M.o.S. as the BnA.1, a version has entered production in an airborne accessory power unit for the Victor B.2 heavy bomber; another A.P.U. is specified for the CL-44.

Reference: March 21, 1958.

Palouste In this engine a 600-size compressor is matched with a 500-size turbine, and the excess air is bled off from a large collection manifold surrounding the combustion chamber. Weighing 204 lb, the Palouste has a normal pressure ratio of 3.88 : 1; a supercharged version is being evolved with a pressure ratio of 5.4:1. The earlier engine powers the Fairey Ultra-light helicopter, and is in mass production for ground-starting and other applications fitted either in trolleys or airborne pods.

Turmo A free-turbine turboshaft engine, the Turmo is rated at 400 h.p. for a weight of 234 lb with direct drive or up to 343 lb according to the number of stages of gearing in the reduction gear. Air is induced through a pair of rectangular inlets at the front end and the exhaust is taken away through either one or two lateral ducts flanking the reduction gear and rear output shaft. Provision is made for a very wide range of accessories. A batch of Turmo 600s has been built for the Saunders-Roe P.531 Mk 1 helicopter and additional engines will be produced for this application. Turmos have also been supplied to Kaman Aircraft for installation in the K-600-4 helicopter, in which the Turmo drives a Boeing compressor which feeds air to pressure-jets at the blade tips.

A.129 The existence of a ready-made two-stage transonic axial compressor, with characteristics excellently matched to the Blackburn Turmo free-turbine engine, has enabled Blackburn to evolve this extremely attractive powerplant relatively quickly and cheaply. As far as possible the engine continues the standardization inherent in the Blackburn family by employing a virtually unchanged central portion, but a second stage has been added to the compressor turbine to provide the increased shaft power required. With the A.129 Blackburn have switched to a truly annular intake, and the accessories are disposed around the casing of the axial compressor. The inlet guide vanes have variable incidence and a torquemeter can be fitted to the output gearbox.

The gas-producer portion was first run as a turbojet in July last year, and the complete A.129 was run on the bench at Brough in August at an initial rating of 840 s.h.p. Testing has since proceeded very satisfactorily, and after slight modifications to the turbine the engine will be re-rated at the design power of 970 s.h.p. It is likely that the first production version will be intended for helicopters, in which it will be more important to provide a constant shaft power of about 700 s.h.p. at an output speed of 6,000 r.p.m. in adverse conditions of altitude and temperature.

Substitution of Nimonic 105 for the Nimonic 90 currently employed in the first- and second-stage turbine rotor blading will enable the engine to run at a turbine inlet temperature 50 deg K higher than at present, thus permitting the maximum i.s.a. rating to be raised to 1,050 s.h.p. The next stage of development will centre around the axial compressor, and research currently in hand should enable the tip speed of this unit to be appreciably raised above the present level of 1,200ft/sec. The resulting higher pressure and increased mass flow are expected to result in a rating of 1,150 s.h.p. At a still later stage it is anticipated that air-cooled turbine rotor blades will be introduced to permit still higher temperatures and an increase in rating to at least 1,200 s.h.p.

BRISTOL SIDDELEY *Bristol Siddeley Engines Ltd., St. James's Street, London, S.W.1.* Notwithstanding the fact that the partners in this great enterprise were themselves originally portions of large rival industrial organizations, Bristol Siddeley Engines has been formed by the complete amalgamation of two companies in a manner which the British aviation scene has not previously witnessed. The constituent firms are Armstrong Siddeley Motors Ltd. (member of the Hawker Siddeley Group) and Bristol Aero-Engines Ltd. (subsidiary of the Bristol Aeroplane Company).

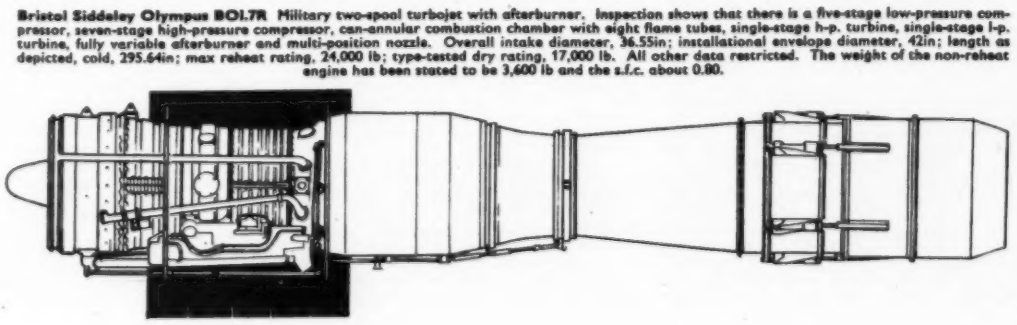
Early last year Bristol Siddeley Engines was formed as a token company to control the technical collaboration between the design and sales teams of A.S.M. and Bristol; but various factors—including the importance of the contract for the propulsion of the TSR.2 aircraft—have caused the two firms to merge into one. All the share capital is held jointly between the parent organizations of the two partner-firms and the directors of the new company have likewise been drawn from Bristol and Coventry. Bristol Siddeley believe that they are third in terms of manpower among the aero-engine concerns of the western world, and in terms of research and development and production facilities are probably first. The following text is divided into engine developments centred in Bristol and in Coventry; in our next such review this sub-division should not be necessary.

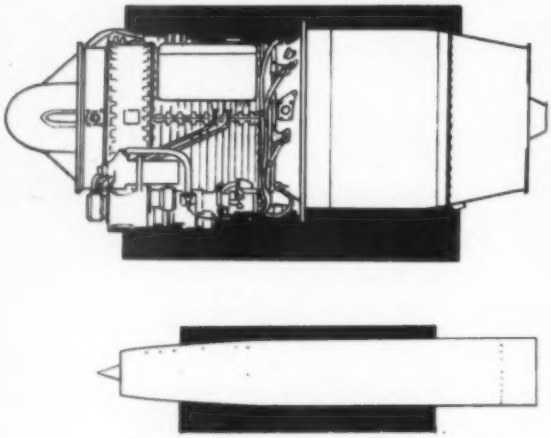
Programmes in Bristol (originally Bristol Aero-Engines):—

Olympus First run in 1950 at a rating of 9,140 lb, this two-spool turbojet has since been developed to a remarkable degree; today, it is an entirely different engine, delivering well over twice as much thrust in conjunction with an extremely competitive specific consumption and enviable reliability. The first-generation, or 100 series, Olympus were delivered between 1953 and 1956 as the powerplant of the Vulcan B.1 bomber. The initial production version was the Olympus 101 rated at 11,000 lb dry; this was succeeded by the Mk 102 (with a zero-stage on the compressor) rated at 12,000 lb, and later by the slightly hotter Mk 104 rated at 13,000 lb. Total hours on these engines are at least 100,000, over 60,000 of which have been logged during Bomber Command Vulcan operations. Current overhaul time of the 101 is 450 hr, with selected engines being run to 600; 102s have been held to 300 hr for conversion to 104 standard at the first major overhaul.

A complete redesign led to the 200 series of second-generation engines in which, notwithstanding a reduction in the number of compressor stages, the thrust has been raised by some 50 per cent with no corresponding increase in engine weight. These second-generation Olympus are undoubtedly among the finest turbojets in the world; their development has been outstandingly successful, and already the dry thrust of engines of this family has risen from 16,000 lb to classified figures well into the 20,000 lb bracket. Production is centred on the BOl.7 Mk 201 illustrated. These engines power the Vulcan B.2 and are

Bristol Siddeley Olympus BOl.7R Military two-spool turbojet with afterburner. Inspection shows that there is a five-stage low-pressure compressor, seven-stage high-pressure compressor, can-annular combustion chamber with eight flame tubes, single-stage h-p. turbine, single-stage l-p. turbine, fully variable afterburner and multi-position nozzle. Overall intake diameter, 36.55in; installational envelope diameter, 42in; length as depicted, cold, 295.64in; max reheat rating, 24,000 lb; type-tested dry rating, 17,000 lb. All other data restricted. The weight of the non-reheat engine has been stated to be 3,600 lb and the s.f.c. about 0.80.





Bristol Siddeley Orpheus BOr.12 Military single-shaft turbojet. Multi-stage compressor, can-annular combustion chamber and (probably) single-stage turbine. Overall diameter, 32.4in; length as depicted, cold, 98.325 in; dry weight, 1,100 lb; max sea-level rating, 6,810 lb dry. Other data are restricted. The BOr.12SR gives 8,000 lb thrust with simple reheat.

Orpheus BOr.3 Mk 803 (not illustrated). Military single-shaft turbojet similar in general appearance. Overall diameter, 32.4in; length, intake to exhaust cone, 75.45in; equipped dry weight, 825 lb; max sea-level rating, 5,000 lb at 10,000 r.p.m. (s.f.c., 1.06); corresponding mass flow and pressure ratio, 84 lb/sec and 4.4:1.

Bristol Siddeley Thor BT.1 Supersonic ramjet for propulsion of the Bloodhound surface-to-air missile. Double-shock intake, ram-driven fuel turbo-pump feeding annular injection manifold and convergent/divergent fixed-geometry nozzle. Overall diameter, 15.75in; length, 94.5in; approximate equivalent horse-power, 130,000 at Mach 3 at sea-level; all other data are restricted.

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shortly to go into service with Bomber Command. With a fully variable Solar afterburner, engines of this family can give greatly augmented thrust, and even at an early stage the BOl.7R was rated at a reheat thrust of 24,000 lb. Early this year it was announced that the Olympus had been selected as the powerplant of the Vickers/English Electric TSR.2 multi-purpose tactical aircraft for the Royal Air Force.

References: July 4, 1952; Dec. 9, 1955 (history and description of 100 series); Feb. 15, 1957 (note on 200 series); Mar. 7, 1958 (extensive report on service experience of 100 series).

Orpheus This simple single-shaft turbojet was first run on December 11, 1954, and flew as the powerplant of the prototype Folland Gnat light fighter the following July at an initial restricted rating of 3,285 lb. The first generation of Orpheus comprise the 700 series of engines for the Folland Gnat (at the BOr.2 rating of 4,520 lb) and the 800 series of power-plants (at the BOr.3 rating of 4,850/5,100 lb) for a wide range of military and civil aircraft. The engine illustrated is in production at Bristol for the Fiat G.91 light attack machine for NATO, and licences for its manufacture are held by Fiat (Italy), B.M.W. (West Germany), Hindustan Aircraft (India), and, as extensions of earlier agreements, SNECMA (France) and Wright Aeronautical (U.S.A.). Total running time of these engines amounts to some 15,000 hr, and BOr.3s with user squadrons are being sampled to establish an initial overhaul life of 150 hr.

A de-rated version intended for training aircraft, such as the Gnat T.1 and Fuji TIF-2, is the BOr.4 or Mk 100 rated at 4,230 lb. Other variants of these first-generation engines include a transport version (the BOr.3/5 Mk 810, rated at 5,100 lb and incorporating bleed-air anti-icing and additional accessories), and a full reheat version of the 700 series which might well prove suitable for the projected Gnat Mk 2.

For the future, a revised series of Orpheus is now on test in which major modifications, apparently including the addition of a zero stage on the compressor, raise both the mass flow and pressure ratio. The most important member of the new family is the BOr.12, which has easily achieved its brochure thrust of 6,810 lb at the design turbine-entry temperature and with a specific consumption well below the estimated value. Flight testing and the completion of a full type test on this engine should take place during 1959, and production deliveries are scheduled to be made in about twelve months' time. As the BOr.12SR the engine is being offered with Bristol simplified reheat for military aircraft, in which form it will have an initial afterburning rating of 8,000 lb. A commercial variant of the BOr.12 would weigh 1,220 lb (120 lb more than the military engine) and with a two-position nozzle would be rated at 7,130 lb dry. Fan derivatives of the Orpheus are also believed to be under development, and a suggested configuration consists of matching upstream stages from the low-pressure compressor of an Olympus with an Orpheus gas-producer.

References: July 5, 1957; history and description; Feb. 13, 1959, extensive outline of development and cutaway drawing.

Proteus During the past ten years the design of the Proteus has been radically altered and improved and, although handicapped by its early conception, the current Proteus is undoubtedly the most reliable large turboprop in the world, besides being a magnificent piece of machinery in its own right. The first version to enter service was the Mk 705 which, as the powerplant of the 15 Britannia 102s of B.O.A.C., started carrying fare-paying passengers in February 1957. These engines are rated at 3,480 s.h.p. (3,900 e.h.p.) and during the 24 months that they have been in service their overhaul life has risen from 500 to 2,000 hr. This rate of progress is unequalled by any other aero engine, civil or military, piston or turbine, and Bristol Siddeley and B.O.A.C. expect appreciably longer periods to be authorized during the coming year. An uprated version of the 705 is the Proteus 706, and a modification to the compressor results in the Proteus 716 rated at 4,440 e.h.p.

For the bulk of the production Britannias the more powerful Proteus Mk 755 was evolved. This engine differs from the 705 chiefly in having improved material specifications (including Nimonic 100 blades in the first turbine stage) and a redesigned power-turbine assembly; these changes permit an increase in flame temperature to give a brochure figure of 4,120 e.h.p. The production engines have consistently given at least 40 h.p. more, the shaft power being 3,705. Last year the 755 was succeeded in production by the 761, with slightly redesigned compressor entry guide vanes and electro-polished compressor rotor and stator blading. These improvements combined to raise the mass flow and pressure ratio to give a 3 per cent improvement in specific consumption, while at the same time enabling a rating of 4,210 e.h.p. to be established at a reduced compressor speed. The Proteus 762 has a re-calibrated control unit and slightly different fuel injectors which permit take-off power to be raised to 4,350 e.h.p. The present standard production engine (series 765 or 766) differs only by an adjustment to the governor setting to give greater cruising power, together with a slight increase in take-off power to 4,445 e.h.p. All 761 engines are tested at the latter rating before delivery, and can be converted readily in the field to the 765 configuration. A related engine is the military Proteus 255 fitted to the 20 Britannia 253s of R.A.F. Transport Command. Likewise rated at 4,445 e.h.p. this engine has water injection to provide maximum power in adverse altitude/temperature conditions.

Future production will centre upon the engine for which data are given in col. 3. This series 770 engine is now in final development, and incorporates labyrinth seals on both stages of the compressor turbine together with aerodynamic improvements which modify the loading on the second stage of the power turbine. The 765 can readily be converted to 770 standard at major overhauls. Mention should also be made of the 3,800 h.p. Marine Proteus fitted to the *Brave* class of fast patrol boats of the Royal Navy. Several hundred Proteus have now been delivered. At the beginning of this year Britannia engines had accomplished 482,000 hr and the total Proteus running time is today approximately 550,000 hr.

References: June 6, 1952 (full description of 705); July 11, 1958 (extensive review of service experience).

Bristol Siddeley Proteus Mk 770 (not illustrated). Commercial free-turbine turboprop. Compressor with 12 axial stages and one centrifugal stage, eight combustion chambers, two-stage high-pressure compressor turbine and two-stage low-pressure power turbine. Overall diameter (around bulkhead ahead of intake), 40.1in; length from propeller-cone fitting line to tip of jet-pipe bullet, 113.23in; dry weight to EDM.25, 2,900 lb; max sea-level rating, 4,130 s.h.p. (4,615 e.h.p.) with s.f.c. of 0.56 lb/hr/e.h.p.; max cruise, 25,000ft at 300 kt, 2,202 s.h.p. (2,640 e.h.p.) at 11,650 compressor r.p.m. with s.f.c. of 0.484 lb/hr/e.h.p.

Ramjets During the past ten years intensive development of ramjets has taken place at Bristol, and the company can fairly claim to be the most experienced in this field in the western world outside the U.S.A. The first Bristol ramjet was flown in 1952. Since that date development has centred upon the 15.75in unit designated BT.1 Thor; in various versions this is the standard powerplant of the twin-engined Bloodhound (Red Duster) surface-to-air missile now in production for R.A.F. Fighter Command and Sweden. Many hundreds of test firings of powerplant-development vehicles and test vehicles associated with the Bloodhound produced an exceptional degree of reliability even before firings of the production-type missile began.

In order to achieve uniform flow to the annular centrebody-type intake, and to permit the necessary cooling airflow over the tailpipe, the Thor is designed for external pylon mounting. In the Bloodhound it is carried on short struts above and below the body; all fuel and electrical connections are made adjacent to the rigid front mounting, and the rear anchorage provides for thermal expansion. Ignition is achieved in the Bloodhound by pyrotechnic flares, and the system has been found virtually 100 per cent reliable. The Thor fuel system consists of a ram-air turbine-driven centrifugal pump, a fuel/air ratio control and a Mach number control which reduces the fuel supply when the chosen cruise Mach number is exceeded.

Thor has been in full production for a considerable period and a larger unit, giving something like twice as much power, has now been publicly displayed. This is the 18in BRJ.801 and it may well be applied to a developed version of the Bloodhound missile. Bristol are now also thinking in terms of a cruise ramjet. Studies have been published showing very plausible supersonic-transport projects, incorporating multiple internal ramjets with design points between Mach 3 and Mach 5 at 60,000 to 80,000ft.

Programmes in Coventry (originally Armstrong Siddeley Motors):—

Double Mamba Possibly the last in a unique family of double-turbine powerplants continuously developed since 1945, the current mark of Double Mamba in production is the ASMD.8 Mk 112. This may only be described as "fitted to the latest types of Gannet," and consists of two ASM.8 Mamba power sections with independent drives to the two units of a counter-rotating, coaxial propeller.

The axial compressors have 11 stages and pass a total mass flow (both units) of 42 lb/sec; the annular combustion chambers each have 12 vaporizing burners and the turbines have three stages. Net dry weight is 2,500 lb, and maximum rating 3,880 e.h.p. with a specific consumption of 0.67 lb/hr/e.h.p.

References: Mar. 31, 1949 (initial version); Mar. 4, 1955 (development history).

Gamma The result of some years of hard work was the very successful firing—at the first attempt—of the first Black Knight re-entry research vehicle at Woomera in September 1958. The powerplant of this vehicle is the Gamma 201.

The Gamma engine was developed from an R.A.E. design. It incorporates four combustion chambers arranged uniformly around the central vehicle support on trunnions in order

that they may be pivoted, by hydraulic actuators, about axes that radiate from it. All four trunnions are hollow, and H.T.P. and kerosine are pumped through the inner and outer trunnions respectively. The kerosine is admitted into the combustion chamber as soon as a pressure rise indicates decomposition of the H.T.P. Prior to this, nitrogen is blown through the fuel passages to prevent reaction in them between the peroxide and the incoming fuel. The nitrogen supply is disconnected automatically as the vehicle rises from the launching pad.

Each combustion chamber is fed with propellants by its own turbopump unit, the four units being joined at the centre by a common H.T.P. manifold. This forms a rigid cross which is attached to the structure of the vehicle at each of the fuel-pump suction elbows. The centrifugal impellers of the peroxide and fuel pumps are mounted at opposite ends of the shaft which carries the associated axial-flow turbine rotor. H.T.P. is decomposed in a separate catalyst pack to provide a jet of hot gas which impinges on the turbine to drive the pumps. To start the engine, H.T.P. is supplied under pressure for this purpose from a ground installation, which is disconnected automatically as the vehicle rises from the launcher pad. By this time the H.T.P. pump pressure is high enough to supply peroxide for the turbine through a control valve. Two of the turbopump units drive hydraulic pumps through kerosine-lubricated gear reduction units.

Reference: Oct. 17, 1958 (Black Knight).

P.181/182 These are the most important new gas turbines by Bristol Siddeley to reach the running stage. Both employ the same compressor, combustion chamber and turbine, and are shaft turbines in the 1,000 h.p. class; the P.181 is being developed to power rotorcraft and the P.182 is a turboprop for fixed-wing aircraft. Development started more than two years ago but the company did not release drawings until they were sure they had reached the optimum configuration; and, as was outlined in our issue of February 21, 1958, the layout of these engines has changed completely during their formative period.

The compressor comprises two subsonic axial stages followed by a centrifugal stage. The combustion chamber is an annular assembly, folded back around the turbine to increase safety and reduce length, with 12 Armstrong Siddeley vaporizing burners. A two-stage turbine drives the compressor and an independent single-stage power turbine drives the rotor or propeller gearbox, the latter (in the P.182) being at the front and driven through a central shaft. Beneath the compressor casing is the accessory gearbox, driven at 0.25 compressor r.p.m. The oil tank is cast integral with the upper half of the compressor casing, the system having a flood feed (750 gal/hr) and being fully scavenged. An electric starter is fitted (i.p. air or i.p.n. optional) and de-icing is effected by air bleed (P.181) or by both hot air and electric means (P.182).

Both engines have been designed to provide exceptional robustness, inherent safety, simplicity and compact drives. The P.181 commenced test-bed running last September 1 and is scheduled to begin flight testing in an existing helicopter design in the near future. Bench running of the P.182 is expected to commence this summer, with first flight tests following shortly thereafter.

Bristol Siddeley P.182 (not illustrated). Company-sponsored turboprop. Compressor with two subsonic axial stages followed by single centrifugal stage, annular combustion chamber with 12 vaporizing burners, two-stage compressor turbine and single-stage power turbine. Overall carcass diameter, 27.45in; overall length, 70.2in; dry weight, "including certain items not always included in engine weights," 600 lb; max rating, sea level, static, i.s.a., 5 min, 1,100 s.h.p. + 200 lb thrust at compressor- and power-turbine speeds of 20,000 r.p.m. (both) with s.f.c. of 0.69 lb/hr/s.h.p. or 0.65 lb/hr/e.h.p.; typical max cont. rating at 200 kt, i.s.a., at 20,000ft, 650 s.h.p. + 55 lb thrust with s.f.c. of 0.595 lb/hr/e.h.p.

PR.23 One of the latest developments by the very experienced rocket team at Ansty, the PR.23 is a small and self-contained package intended for such applications as the provision of vernier thrust for ballistic missiles and as a performance booster for combat aircraft. Few details have been released beyond the fact that it operates on H.T.P. and kerosine and is smoothly controllable down to approximately 30 per cent of the maximum rating. As the drawing indicates, the turbopump and control system are grouped in a pressed-sheet box to which the chamber is attached.

Sapphire Like most British turbojets, this fine axial single-shaft engine has been developed in two major families. The first generation, or 100 series, was made in Armstrong Siddeley's Brockworth factory in very large numbers for the Hunter F.2 and F.5 and various marks of Javelin. Some 10,000 similar engines have been licence-produced by Wright Aeronautical in the U.S.A. (*q.v.*). For more than two years production has been centred on the 200-series Sapphires, of ASSa.7 rating, for the Javelin FAW.7 and Victor B.1. Current production includes a proportion of Sapphire 7LR engines for the Javelin FAW.8.

Equipment includes the following: fuel system maximum-speed governor, air/fuel ratio control unit, and flow control unit; automatic jet-pipe temperature control; pressure lubrication to the three main bearings and accessory drives, all oil being fully scavenged and cooled in a high-pressure fuel/oil heat exchanger (full normal lubrication is maintained during sustained inverted flight); an i.p.n. or electric starter; compressor-bleed heating of the front end; and compressor bleed from five points for cabin pressurization and heating and fuel-tank pressurization. The Sapphire 7LR incorporates a simplified reheat system which burns the excess fuel available from the main fuel pump at altitude, to provide 12 per cent augmentation above 20,000ft. The engine has a normal power lever which can be pushed to an override stop to bring in the reheat. The nozzle is a two-position assembly containing 27 segments operated by 12 pneumatic actuators.

References: Jan. 6, 1956 (history and description of 100 series); Nov. 9, 1956 (history and description of 200 series).

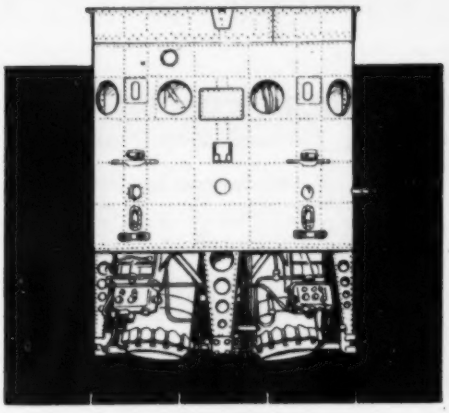
Bristol Siddeley Sapphire 201 ASSa.7 (not illustrated). Military single-shaft turbojet. Thirteen-stage compressor, annular combustion chamber with 24 vaporizing burners and two-stage turbine. Overall diameter, 37.55in; overall length, 131.6in; equipped dry weight, 3,050 lb; max rating, 11,000 lb dry with mass flow of 168.5 lb/sec and s.f.c. of 0.86; the ASSa.7LR, with simple reheat, has a weight of 3,180 lb and a max rating of 12,300 lb with an s.f.c. of 1.20.

Viper Now firmly established as an efficient and very reliable turbojet, operating at moderate turbine temperatures, the ASV.8 Mk 102 of 1,750 lb rating is entering R.A.F. service as the powerplant for the Jet Provost T. Mk 3. The centre sections of these engines are now modified to incorporate the zirconium casting instead of the previous welded sheet-metal structure, effecting a reduction in cost. The Viper 8 will power the Jindivik Mk 2B, which is aerodynamically similar to the Jindivik Mk 3 having a pitot-type intake giving more efficient breathing at high altitudes. Similar engines powered the Fairchild XSM-75 Bull Goose prototypes.

The ASV.9 is an uprated version of the Viper 8, operating at a higher turbine temperature giving a maximum thrust of 1,900 lb. This engine has been type tested, and was successfully operated under tropical conditions during the recent Middle East demonstration tour by a Jet Provost.

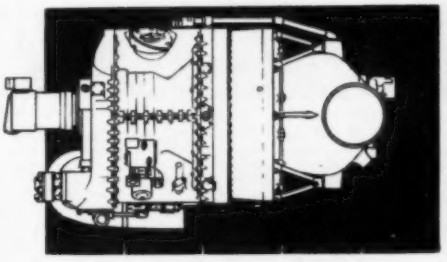
The ASV.11 engine was designed to meet a requirement for a turbojet offering appreciably greater thrust. Since it was considered desirable that the Viper 11 should be installationally interchangeable with the Viper 8 (jet-pipe excepted) the major constructional difference between the two engines is confined to a redesigned compressor, of drum/disc construction, with a reduced hub diameter to give an increased mass flow.

Development was initiated as a company venture at two ratings, the ASV.10 rating of 2,000 lb thrust and the ASV.11 of 2,500 lb thrust, the object being to take advantage of the extremely moderate flame temperature of the ASV.10 during the early stages of development. With the background experience obtained with the Viper 8 engines the progress has been so satisfactory that Viper 10 development has been suspended, and activities concentrated on the ASV.11. The ASV.11 was first publicly demonstrated in a Jet Provost at the 1958 S.B.A.C. Show, and versions of this series will

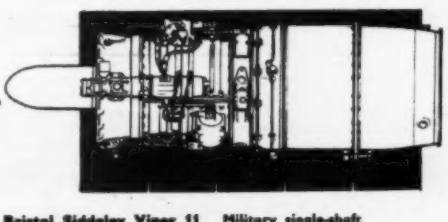


Bristol Siddeley Gamma Mk 301 Liquid-propellant rocket propulsion package, with four gimbal-mounted chambers each individually fed by its own turbopump with H.T.P. and kerosine. Overall diameter, 36in; length as depicted, 38in; dry weight of complete engine compartment, approximately 700 lb; thrust rating, 16,400 lb at sea level, rising to over 19,000 lb at altitude.

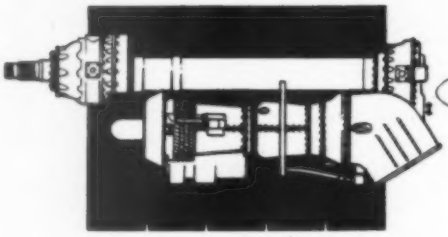
Bristol Siddeley PR.23 Liquid-propellant rocket motor. Single, fixed, regeneratively cooled chamber fed by turbopumps with H.T.P. and kerosine from remote tankage, mounted in one package complete with control system. Overall enclosing diameter, 8.25in; nozzle external diameter, 4.25in; overall length, 39in; dry weight, 30 to 32 lb; thrust, variable from 500 to 800 lb at sea level; specific impulse, 207 at sea level, 250 at 30,000ft and 264 at 60,000ft.



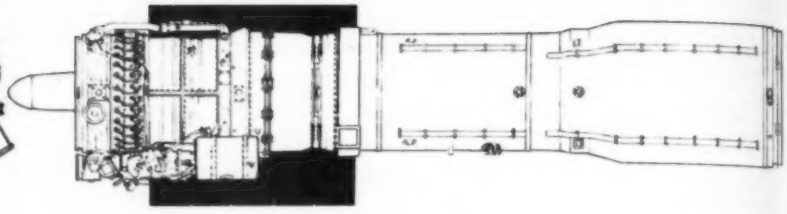
Bristol Siddeley P.181 Company-sponsored turboshaft engine. Compressor has two subsonic axial stages followed by single centrifugal stage, annular combustion chamber with 12 vaporizing burners, two-stage compressor turbine and single-stage power turbine. Overall carcass diameter, 27.45in; overall length as depicted (rear drive), 60.82in; dry weight, "including certain items not always included in engine weights," 550 lb; max performance at sea level, static, arbitrarily held to 800 s.h.p. + 155 lb thrust at 20,000 compressor r.p.m. and 14,600 power-turbine r.p.m., maintained up to 3,750ft at i.s.a. + 30 or up to 11,000ft at i.s.a., the fuel consumption (i.s.a + 30 at 3,750ft) being 575 lb (72 Imp. gal)/hr at s.f.c. of 0.72 lb/hr/s.h.p.; max cont. rating is 665 s.h.p. + 130 lb. (i.s.a. + 30 at 3,750ft) with s.f.c. of 0.74; equivalent ungated sea-level i.s.a. ratings would be 1,020 s.h.p. with s.f.c. of 0.71 and 930 s.h.p. with s.f.c. of 0.72.



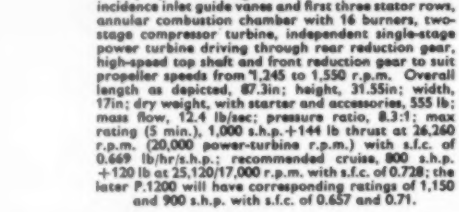
Bristol Siddeley Viper 11 Military single-shaft turbojet. Seven-stage compressor, annular combustion chamber with 24 vaporizing burners and single-stage turbine. Overall diameter, 24.55in; intake external diameter, 18.5in; length, exclusive of nose bullet, 63.7in; dry weight, 500 lb; max rating, 2,460 lb dry at 13,400 r.p.m. with mass flow and pressure ratio of 42 lb/sec and 3.85:1 and s.f.c. of 1.115.



de Havilland Gnome P.1000 Company-sponsored turboprop. Ten-stage compressor with variable-incidence inlet guide vanes and first three stator rows, annular combustion chamber with 16 burners, two-stage compressor turbine, independent single-stage power turbine driving through rear reduction gear, high-speed top shaft and front reduction gear to suit propeller speeds from 1,245 to 1,550 r.p.m. Overall length as depicted, 87.3in; height, 31.55in; width, 17in; dry weight, with starter and accessories, 555 lb; mass flow, 12.4 lb/sec; pressure ratio, 8.3:1; max rating (5 min.), 1,000 s.h.p.+144 lb thrust at 26,260 r.p.m. (20,000 power-turbine r.p.m.) with s.f.c. of 0.669 lb/hr/s.h.p.; recommended cruise, 800 s.h.p. +120 lb at 25,120/17,000 r.p.m. with s.f.c. of 0.728; the later P.1200 will have corresponding ratings of 1,150 and 900 s.h.p. with s.f.c. of 0.657 and 0.71.



de Havilland Gyron Junior DGJ.10R Military single-shaft turbojet with reheat. Axial compressor (apparently with eight stages), annular combustion chamber with 13 upstream burners, turbine (apparently with two stages) and fully variable afterburner with con-di nozzle. Max overall diameter of engine, 32.3in; max diameter of afterburner, 36in; nozzle size, 27.8in (throat) and 32in orifice fully opened; overall length, 190.0in without intake bullet; all other data restricted, but the dry and reheat ratings are probably of the order of 10,000 and 14,000 lb.



de Havilland Double Spectre Double-barrel rocket engine for supersonic applications. Two chambers, each fed with H.T.P. and kerosine by turbo-pumps, the lower chamber being infinitely controllable. Overall width, with mounting, 36.6in; height, 37.5in; length, 58.6in; all other data are restricted.

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power the Macchi MB.326, Jindivik Mk 3 and other aircraft.

In the course of Viper 11 development, versions of this engine have been run at temperatures giving maximum static thrusts of 2,700 lb. This variant is referred to as the Viper 12, and proposals for reheat on the engine are being considered.

Reference: Aug. 7, 1953 (history and full description of initial version).

D.H. ENGINES *The de Havilland Engine Co. Ltd., Leavesden, Herts.* Since our last engine review issue the character of this company has changed markedly. The purchase of a licence to develop and produce the American G.E. T58 engine has had a profound effect, and seems likely to generate a considerable volume of business for many years. The big Gyron has faded from the picture, but the Gyron Junior is being intensively developed in two major forms and is now a versatile and highly attractive powerplant. Rocket motors for a.t.o. purposes have been delivered in quantity, and more sophisticated rocket powerplants for cruise propulsion are entering production. Notes on all these engines are appended hereunder. As regards earlier powerplants, limited production is continuing on the Gipsy Major 215 and Gipsy Queen Mk 2, and small numbers of Ghost and Goblin centrifugal turbojets are being delivered to individual order. In addition, the company are engaged in a major conversion programme in modifying the Royal Navy's Ghosts up to Mk 105 standard. These earlier engines have all been described in previous engine review issues.

Gnome Since 1951 D.H. Engines have exchanged technical information with the General Electric Company of America, and in February last year it was announced that the British company would licence-produce the G.E. T58 turboshaft engine. This has at one stroke made available to de Havilland the results of five years and 13,000 hr of bench testing, simulated high-altitude operation, climatic testing, helicopter-rotor rig testing, and many hundreds of hours' flying in three types of single-engined and coupled-engine helicopters, and will undoubtedly enable the anglicized engine, known as the Gnome, to be made available at a very early date. The British engine is being built in both helicopter and turboprop forms to cover the entire field of single and coupled applications in the power range 1,000 to 1,400 s.h.p.

Notes upon the original T58 will be found under G.E. in the American section. The basic helicopter Gnome, designated H.1000 with Ministry of Supply rating DGe.1, is practically identical to the G.E. design, but incorporates British materials and production methods (the latter including a de Havilland blade-rolling technique for quick and low-cost precision forming of profile right from the root radius) and largely British accessories. Parts for the first helicopter Gnomes have been in production for some time. The first run by D.H. of an American-built T58 took place at Hatfield at the end of last August, and since the beginning of this month one of these engines has been flying in a Westland Whirlwind. A batch of British-built Gnomes is at present being assembled; the first of these should run on the bench in May and helicopter Gnomes should enter the flight-test stage and be type tested before the end of the year. Orders for these engines have already been received from the Continent and there is strong British and European interest in double and triple installations and marine versions.

Illustrated here for the first time is the P.1000 turboprop version, which drives a D.H. three-blade 3/2500/4 propeller from 9 to 13ft diameter. This engine is likewise due to run on the bench and start its flight-test programme during 1959, and is likely to be exported in single and double versions and also—with multiple engines coupled by lateral shafting and free-wheel mechanisms—be employed in STOL aircraft, with 3/5000/5 propellers up to 15ft diameter. De Havilland are also investigating the market for a turbojet and an aft-fan version.

Reference: Aug. 15, 1958 (full description and cutaway drawing).

Gyron Junior In 1954 this family of single-shaft turbojets was planned by scaling down the big Gyron to handle approximately 40 per cent as much airflow. The first types of Junior are therefore rated at 7,000 lb thrust, and have been running since August 1955.

It is logical to assume that engines of this series power the Blackburn NA.39 carrier-based strike aircraft. Several of these machines are now flying, and one of them—currently based at the R.A.E. Bedford and soon to move to Hatfield—is assigned to D.H. Engines for powerplant development. In addition, a continuous flight-test programme has been maintained by a Canberra which mounts a Gyron Junior on the port side. An outstanding feature of these engines is the large circumferential bleed manifold around the combustion chamber, from which a huge quantity of air may be supplied for flap blowing and supercirculation (which in the NA.39 is very extensive). A Rotax low-pressure air starter is fitted, and the fuel system is by Dowty incorporating a single-circuit spill burner gallery, a hydraulic all-speed governor and a mechanical top-speed governor, the latter being trimmed by the j.p.t. control. The front end is de-iced by bleed-air controlled by a Teddington twin butterfly valve, and a Lucas pump serves the fuel-operated inlet guide vane actuators.

The engine illustrated is the reheat version of the more advanced DGJ.10. This much more powerful engine incorporates a de Havilland reheat system which gives something like 40 per cent augmentation for a reheat temperature of around 2,000 deg K. It is at once apparent that one or more stages have been added to the compressor, and the inlet guide vanes and first row of stators have their incidence controlled by a function generator supplied with an engine r.p.m. signal. The equipment seen on the DGJ.10 includes a Rotax low-pressure air starter, a Dowty two-circuit spill burner fuel system, a Delaney Gallay fuel-cooled oil cooler, port and starboard power take-offs, twin drive faces for hydraulic pumps and a Hobson-Microjet reheat fuel system and variable nozzle control. The latter has at least three positions: convergent; convergent/parallel with reheat; and convergent/divergent at a specific high supersonic flight Mach number. Napier's flight development establishment at Luton is installing a pair of these engines in a Javelin for flight-test purposes, and this aircraft should fly in the coming summer. Further applications may not yet be stated.

Spectre Most powerful of the D.H. family of H.T.P./kerosine rocket engines, the Spectre is a very highly developed unit existing in various forms, all incorporating integral turbo-pumps feeding the propellants from remote tankage. The chief versions are the DSpe.4, a fixed-thrust a.t.o. package in production for the Vulcan and Victor, and the DSpe.5 fully controllable aircraft unit which has been flown at high supersonic speed and altitude in the SR.53 and is now regarded as fully developed.

The most important member of the family is the Double Spectre, illustrated. This consists of two units, one fully variable and one of fixed-thrust, which are combined in a single powerplant to provide propulsion for a missile (the application may not be stated, but it seems fairly clear that it is the Avro Blue Steel air-to-surface weapon). As the drawing shows, the chambers are so mounted that their thrust lines pass through the c.g. of the vehicle, so that either engine may be shut down without any change in trim. The Double Spectre is virtually completely developed; a photograph of a night firing appears on page 388.

References: Aug. 23, 1957 (DSpe. 5); Feb. 7, 1958 (DSpe. 4); Nov. 14, 1958 (development history).

Super Sprite The first of the D.H. "hot" H.T.P./kerosine rockets, the Super Sprite is a fixed-thrust engine fed with propellants by pressurizing the tanks. The latter form an integral part of a package which is installed in a jettisonable and recoverable nacelle to provide a.t.o. thrust for the Valiant bomber. A large number of these units are in service and production is continuing.

Reference: Aug. 5, 1955 (full description and cutaway drawing).

NAPIER *D. Napier & Son Ltd., London, W.3.* Having, as a result of several years' persistent slogging, established the Eland and Gazelle single-shaft turbine engines as production products, the past year has been largely devoted to refinement and consolidation for the exceedingly diverse applications of these engines. No other aircraft powerplants are currently active projects beyond the brochure stage; extensive development has taken place upon rocket motors (as outlined below) and the company also designed, developed and manufactured a range of ramjet test vehicles (*Flight*, September 30, 1955) under contract to the National Gas Turbine Establishment.

Eland This engine has been developed in three major versions, for fixed-wing transport aircraft, hub-driven helicopters and the unique Fairey Rotodyne convertiplane. All three species of engine utilize essentially identical gas-producer sections.

Fixed-wing As the standard turboprop version, the Eland 504 is certified by the A.R.B. and F.A.A. and is in production for the Canadair 540 transport for the R.C.A.F. Versions have also been planned for the re-engining of the Convair 240/340/440, Constellation, DC-6 and other types. Features include an intake heated by oil circulation, a compressor with aluminium-bronze blading, upstream-injection burners and a three-stage turbine with stators of X40 alloy, wheels of Jessops H40 and rotor blading of Nimonic 100 (first stage) or Nimonic 90 (second and third stages). Starting is effected either electrically or pneumatically; the Eland 504A has a Rotax l-p. air starter matched to the Palouste 504 G.T.C. set, and the Eland 504B has an AiResearch starter supplied by the G.T.C. 85/62 compressor of the same manufacture.

Full type-testing of the Eland 504A for the R.C.A.F. has been completed, and the engine has logged 2,420 hr running in Napier's CV-340 and 440. The full anti-icing programme for A.R.B. and F.A.A. clearance was completed with Napier's Varsity aircraft. The engine has proved its ability to ingest large quantities of water, ice and "standard birds" and to contain a broken turbine blade. A 25 hr type test has been conducted while burning Avgas. These engines are expected to achieve overhaul periods in excess of 1,000 hr by 1960. A version with a higher maximum continuous rating is under development as the 508.

Helicopter A special rear-drive version of the Eland designated E.229 has been evolved for the Westland Westminster helicopter, using a gas-producer similar to that of the turboprop. The propeller reduction gear has been removed from the front end, and a gear-type coupling has been added at the rear of the turbine shaft, leading to a ball coupling which accommodates all aircraft and engine axial expansions. The latter connects with a drive shaft which incorporates a second ball coupling and a special hydraulic clutch. The latter, which is of Napier manufacture, contains two sets of impeller bucket wheels running in engine oil to supply a fluid drive to the rotor gearbox. The engine, hydraulic coupling and primary reduction gearbox are all mounted coaxially, the exhaust gases being ducted away through a lateral jet-pipe. Engine accessories, which include a hydraulic-clutch booster pump, oil-cooler fan and a drive for the aircraft hydraulic pump, are disposed around the intake and are driven by bevel and spur gears from the compressor shaft. The engine is started by an electric starter mounted above the front end of the compressor casing.

In the Westminster two such engines are installed side-by-side. Both are connected to the main rotor gearbox on the centre-line of the aircraft, the hydraulic couplings and primary and secondary gearboxes being airframe-mounted. Automatic engine control is provided by a single lever for each powerplant, separate controls being provided for starting and running up to clutch-in conditions. At present some 140 hr have been logged by the Eland 229s installed in the first Westminster. The data given beneath the drawing are for the slightly revised Eland 229A which is being fitted to the second Westminster, and estimated figures are also given for the E.211 which will be the production Westminster engine. The latter is the variant depicted in the drawing.

Convertiplane For the Fairey Rotodyne a unique powerplant has been evolved, consisting of a complete turboprop to the rear of which is attached an additional nine-stage auxiliary compressor which can be driven through a hydraulic coupling to provide air for the rotor pressure jets. Full details of this engine have been published previously, as noted below. The current NEl.3 engines of the first Rotodyne have completed 330 hr installed running; one pair of engines has been in use for over 100 hr with only trivial problems. The NEl.7 is a more powerful convertiplane engine corresponding approximately to the Eland 504. Its total dry weight is 2,575 lb.

References: July 23, 1954 (full history, description and cutaway drawing); June 13, 1955 (design philosophy); Dec. 20, 1957 (convertiplane version).

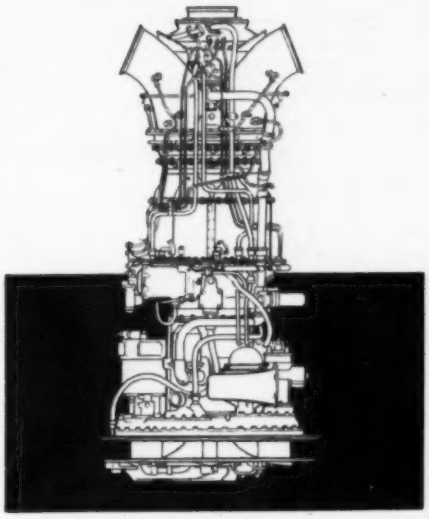
Gazelle No major changes have taken place on this powerplant during the past year, and two main versions are in production for the Westland Wessex (single engine) and Bristol 192 (twin engine) helicopters, respectively for the Royal Navy and R.A.F. All Gazelles are designed for installation in any attitude; the drawing shows an engine mounted vertically, as in the Bristol 192.

Much running has been accomplished in an any-angle cell at Park Royal, and the engine has been proved for tropical operation by employing electric heaters in the test cell, prior to full tropical flight trials which are shortly to commence. Total running time is at present approximately 7,800 hr. Some 840 hr has been run on NGa.2 engines in a Bristol gantry rig and 116 flight hours have been logged by similar engines in the first Bristol 192 to be completed. For the Westland Wessex the NGa.13 has been involved, the chief differences in this engine being the use of "mirror image" turbine blading to turn the output shaft in the opposite direction, and a redesigned reduction gearbox to increase the output ratio from 6:1 to 7:1 to achieve optimum matching between engine and rotor r.p.m. Some 277 hr have been logged by NGa.13s in Wessex helicopters.

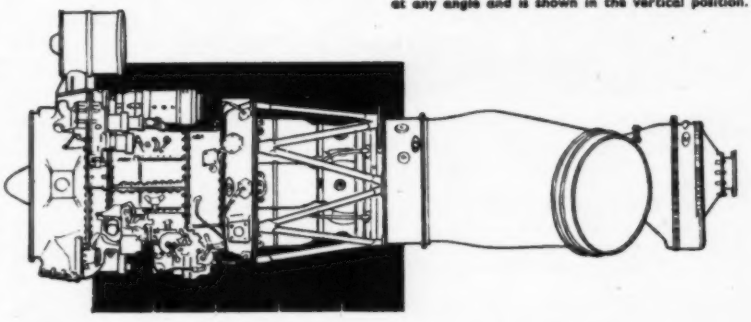
Production engines for both helicopters are being assembled at Netherton (Liverpool). B.T.H. and Napier are co-operating in the development of an i.p.n./cartridge starter for the Gazelle. A large number of failure cases have been simulated during bench running, and gantry trials have been instrumental in setting the torque trips which prevent the free turbine from over-speeding in the event of a loss of load.

Reference: May 10, 1957 (history and full description).

Rocket motors After extensive experience with the development of single-chamber liquid-propellant motors for missiles and test vehicles, Napier have evolved a family of exceedingly neat H.T.P./kerosine rocket

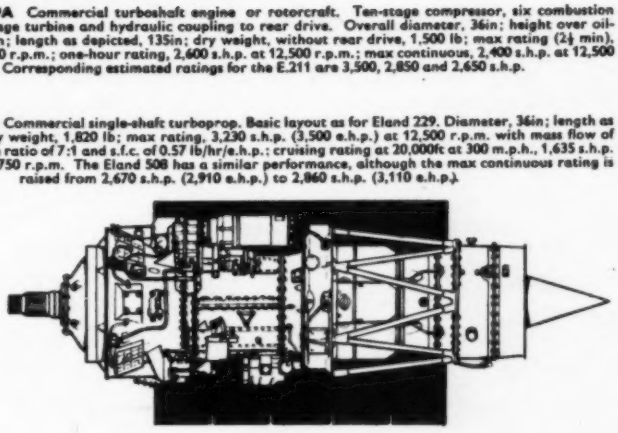


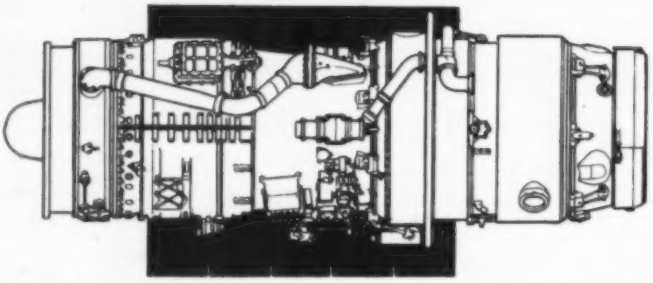
Napier Gazelle NGa.13 Military free-turbine turboshaft engine. Eleven-stage compressor, six combustion chambers, two-stage compressor turbine and single-stage free power turbine. Overall diameter (intake casting), 33.5in; overall height, 70in; equipped dry weight, 865 lb; max rating, 1,800 s.h.p. (5-min limit) at 20,400 compressor r.p.m. with s.f.c. of 0.664, or 1,450 s.h.p. (one-hour) at 19,500 compressor r.p.m. with s.f.c. of 0.703. Note: this engine can be mounted at any angle and is shown in the vertical position.



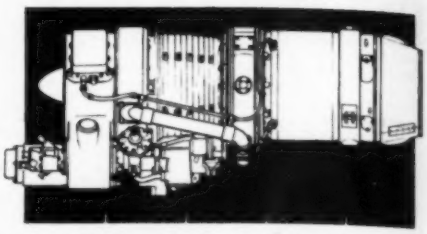
Napier Eland 229A Commercial turboshaft engine or rotorcraft. Ten-stage compressor, six combustion chambers, three-stage turbine and hydraulic coupling to rear drive. Overall diameter, 36in; height over oil-cooler blowers, 51in; length as depicted, 135in; dry weight, without rear drive, 1,500 lb; max rating (2½ min), 3,150 s.h.p. at 12,500 r.p.m.; one-hour rating, 2,600 s.h.p. at 12,500 r.p.m.; max continuous, 2,400 s.h.p. at 12,500 r.p.m. Corresponding estimated ratings for the E.211 are 3,500, 2,850 and 2,650 s.h.p.

Napier Eland 504 Commercial single-shaft turboprop. Basic layout as for Eland 229. Diameter, 36in; length as depicted, 116in; dry weight, 1,820 lb; max rating, 3,230 s.h.p. (3,500 e.h.p.) at 12,500 r.p.m. with mass flow of 35.5 lb/sec, pressure ratio of 7:1 and s.f.c. of 0.57 lb/hr/e.h.p.; cruising rating at 20,000ft at 300 m.p.h., 1,635 s.h.p. (1,800 e.h.p.) at 11,750 r.p.m. The Eland 508 has a similar performance, although the max continuous rating is raised from 2,670 s.h.p. (2,910 e.h.p.) to 2,960 s.h.p. (3,110 e.h.p.).

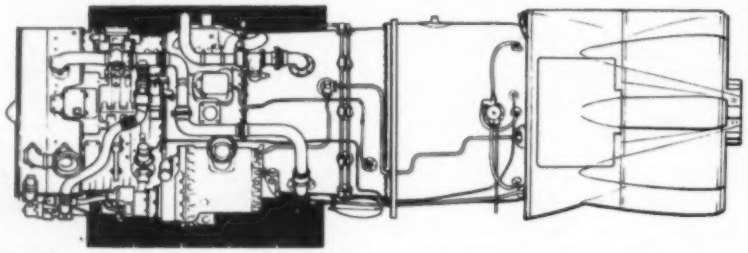




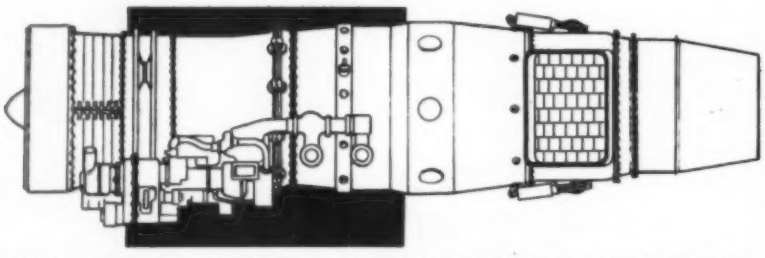
Rolls-Royce Avon RA.29 Mk 527 Commercial single-shaft turbojet. Sixteen-stage compressor, annular combustion chamber with eight flame tubes, three-stage turbine and two-position sound-suppressing nozzle. Installational envelope diameter, 39in; diameter outside intake, 35.7in; overall envelope diameter, 43in; length as depicted, room temp., 125.975in; dry weight, 3,327 lb (including oil and fuel systems, controls and electrics); max sea-level rating, with nozzle in closed position, 11,700 lb at 8,000 r.p.m.; corresponding mass flow and pressure ratio, 173 lb/sec and 9.63:1; max continuous rating, 9,810 lb with s.f.c. of 0.749; low-percentage cruise rating at M 0.74 at 35,000ft, standard day, with nozzle open, 1,820 lb at 6,850 r.p.m. with s.f.c. of 0.885.



Rolls-Royce RB.145 Single-shaft turbojet. Axial compressor with six or seven stages, annular combustion chamber and (probably) single-stage turbine. Diameter 20.25in; overall length as depicted, 65in; max rating, 2,750 lb dry; all other data restricted.



Rolls-Royce Conway RCo.10 Mk 505 Commercial by-pass engine. Multi-stage low-pressure (fan) compressor, multi-stage high-pressure compressor, annular combustion chamber with ten flame tubes, independent high- and low-pressure turbines. Diameter across outside of intake, 37.6in; overall installational envelope diameter, under 47.5in; length from nose to turbine exit cone, 134.21in; max sea-level rated thrust, 17,000 lb (16,500 guaranteed min.); these engines may be recalibrated to give 500 lb additional thrust without internal modification. All other data are restricted. (The drawing shows a Boeing Mk 505, complete with reverser and nozzle, but without the U.S.-supplied cabin turbo-compressor.)



Rolls-Royce RB.141 Commercial high-ratio by-pass turbojet. No details have been released, except for the fact that the thrust of the first series will lie between 12,000 and 16,000 lb, according to application; first deliveries are likely to be rated at 14,300 lb. The five-foot scale in the drawing is approximate.

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motors for aircraft. These units are based upon a regeneratively-cooled chamber rated at 3,000 lb sea-level thrust, and form an outstandingly compact package complete with turbopump and control system. As the Double Scorpion, a twin-barrel package has been flight-tested in a Canberra—which gained a world altitude record while doing so—and a number of these units are in service in Canberras of the R.A.F. engaged upon special duties. The Double Scorpion is also available to provide boost propulsion for the Lightning intercepter. Last year details were given of the Triple Scorpion, a three-barrel unit scarcely larger than the twin-chamber engine. Each fixed-thrust chamber can be individually fired or shut down.

Napier have also taken cold H.T.P. helicopter boost systems to an advanced stage of development. Considerable flight experience has been gained with equipment mounted on a Skeeter 5 helicopter and a boost system has also been designed for the Westland Whirlwind.

Rolls-Royce Dart RDa.7/2 Mk 536-540 Commercial single-shaft turboprop. Two centrifugal compressors in series, seven canted combustion chambers and three-stage turbine. Overall diameter at rear of nose cowl, 33in; max diameter across firewall, 37.9in; length as depicted, 97.64in; dry weight, 1,250 lb fully equipped; max sea-level rating, usually 1,910 s.h.p. (2,100 e.h.p.) at 15,000 r.p.m. with s.f.c. of 0.66 lb/hr/e.h.p.; corresponding mass flow and pressure ratio, 22 lb/sec and 5.62:1.

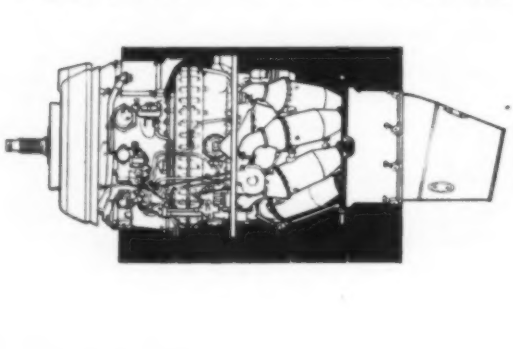
Dart RDa.10 Similar configuration. Slightly longer; dry weight 1,323 lb; max sea-level rating 2,440 s.h.p. (2,660 e.h.p.) at 15,000 r.p.m., with s.f.c. of 0.64 lb/hr/e.h.p. and mass flow and pressure ratio of 25.5 lb/sec and 6.35:1.

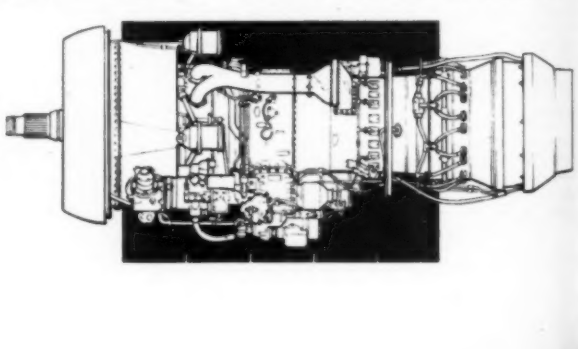
ROLLS-ROYCE *Rolls-Royce Ltd., Derby.* During the past three years this renowned company has consolidated its position as the world's leading producer of gas turbine aero-engines for airline transport operations. At present 54 per cent of the world's turbine airliners (excluding the Communist countries) are equipped or will be equipped with Rolls-Royce powerplants; and this proportion is unlikely to change substantially during the next five years. The company's operations are sub-divided among an aero-engine division, an oil-engine division, a car division, an international division and Rolls-Royce and Associates Ltd. The last-named is engaged in nuclear power reactor engineering, and Rolls-Royce are also one of the three partners in Vickers Nuclear Engineering.

The aero-engine division is by far the largest, with some 34,000 employees (of whom about 8,500 are engaged in research and development). Last September the company's privately financed (£6m) high-altitude test facility for turbojets and turboprops was formally opened, and in this engines can be tested under conditions equivalent to Mach 2.5 and 70,000ft. Derby remains the headquarters of the company and of the aero-engine division, and the major part of the work upon military and civil aircraft engines, rocket engines and nuclear work is centred in that town. The Scottish group of factories is engaged in the bulk production of military Avon turbojets, together with spares and overhauls for the earlier centrifugal turbojets and the support of all piston engines. Other establishments are Ilkeston and Mountsorrel, near Derby (jigs, tools and sheet metal), Barnoldswick, Lancs (research and development) and Hucknall, Notts (flight development establishment). Rolls-Royce also manage the Ministry of Supply rocket test site at Spadeadam, Cumberland.

Avon (military) Over 1,750,000 hr has now been logged in squadron service by the thousands of Avon axial turbojets which power

Rolls-Royce Tyne RTy.1 Mk 506 Commercial two-spool turboprop. Six-stage low-pressure compressor, nine-stage high-pressure compressor, annular combustion chamber with ten flame tubes, single-stage high-pressure turbine and three-stage low-pressure turbine. External diameter over intake, 35.3in; overall installational envelope diameter, 40.5in; length as depicted, room temp., 110.154in; dry weight, 2,220 lb with all equipment; max sea-level rating, 4,500 s.h.p. (4,985 e.h.p.) at 15,250 r.p.m.; corresponding mass flow and pressure ratio, 46 lb/sec and 13:1; typical cruising rating, 425 m.p.h. at 25,000ft, standard day, 2,455 s.h.p. (2,685 e.h.p.) with s.f.c. of 0.405 lb/hr/e.h.p. Ratings of later Tynes are given on p. 396.





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such aircraft as the Canberra, Hunter, Valiant, Commonwealth Sabre, Lightning, Sea Vixen, Scimitar, Comet 2, Swift, Lansen and Draken. Avons of various types are being constructed by Commonwealth Aircraft Corporation (Australia), Svenska Flygmotor (Sweden) and F.N. (Belgium).

In its first-generation (100 series) form the Avon has a twelve-stage compressor, eight tubular combustion chambers and a two-stage turbine. Electric or cartridge starting is employed and later models of these engines incorporate compressor-bleed anti-icing. Afterburning versions are employed in the Swift and Lansen. Maximum ratings very from 6,500 to 8,100 lb dry, and the RA. 7R, a typical reheat version, has an afterburning rating of 9,500 lb.

In 1953 production deliveries began on the first of the 200 series. These second-generation Avons differ from their predecessors in having a fifteen-stage compressor, and a can-annular combustion system which reduces the maximum girth of the engine and accommodates a considerably increased mass-flow. Engines of this series are clearly used in the Valiant, Sea Vixen, Scimitar and recent versions of the Hunter and Canberra, and after-burning variants—supersonic engines, with steel compressor casings—are employed in the Lightning and Draken. Like the later 100-series Avons, equipment includes an electric, pneumatic, fuel/air or cartridge starter, together with a Lucas fuel system, full all-weather protection, an integral oil tank and an oil cooler in which the cooling medium is high-pressure fuel. The first 200-series engines to come into production were rated at 10,000 lb dry at 8,000 r.p.m., and had specific fuel consumptions below 0.9. The latest versions (i.e. those remaining in production) undoubtedly employ air-cooled turbine blades, which have permitted a considerable jump in turbine-entry temperature to be conquered without an adverse effect on blade life. Tens of thousands of such blades are now in British service, and it seems likely that virtually all of them are fitted in late-model military Avons. The only rating which may be quoted for such units is the 11,250 lb dry thrust for an RA.24, but substantially higher ratings may be anticipated from the latest military engines. As already noted, Rolls-Royce/Lucas afterburners are fitted to both the upper and lower engines of the Lightning intercepter; the nozzles of these engines have twelve petals, and their area is infinitely variable according to the reheat selected by the pilot's power lever. In the Scimitar strike/fighter it is logical to suppose the incorporation of a circumferential bleed manifold around the combustion chamber, in order to provide the huge quantities of air required for supercirculation purposes.

References: Dec. 16, 1955 (full description of 100 series); Oct. 11, 1957 (full description of 200 series).

Avon (Civil) For airline transport purposes Rolls-Royce have evolved an entirely new range of Avon powerplants under the Ministry of Supply rating of RA.29. Although the central portions of these engines are generally the same as those of the 200-series military units, both the mass flow and pressure ratio have been markedly increased by adding a zero-stage to the compressor. As a result an initial guaranteed minimum thrust of 10,500 lb dry was established at an early date for the RA.29/1, with a flame temperature so low as to permit the attainment of an extraordinarily low specific fuel consumption coupled with an exceptional component life. The basic 29/1 has for some 18 months been in production as the Mk 522 (Caravelle), Mk 524 (Comet 4) and Mk 525 (Comet 4B). Largely as a result of intensive route trials with Avon 524s mounted in a pair of Comet 2E aircraft, the Avon was cleared by the A.R.B. and F.A.A. for an initial overhaul life of 1,000 hr prior to its entry to service (a unique distinction). Since October 4 the Mk 524 has been in scheduled service on the North Atlantic routes of B.O.A.C., and at the time of writing there has been no service delay attributable to the powerplants.

Production engines are at present being delivered for 33 Comets and 50 Caravelles. Following a well-established policy, Rolls-Royce employ light alloys extensively throughout the compressor. The first ten rotor stages are of aluminium alloys and the final six are of titanium; aluminium alloys are used for the first eleven stator stages and the final five are of titanium (steel in the Mk 525 engines of B.E.A.'s Comet 4Bs). Engines so far delivered have recorded mean corrected thrusts in excess of the 10,500 lb guaranteed value, the figure for the first batches being 10,650 lb; moreover, the specific fuel consumption is even better than the very competitive brochure figure of 0.775 at 10,500 lb, the mean achieved figure being 0.76 at this value and 0.72 at 80 per cent power.

Before the RA.29/1 entered scheduled service a type test had already been successfully run on the RA.29/3. This engine is virtually identical with the 29/1, except for a minor change in material specifications to permit a higher turbine inlet temperature and the addition of a simple flap between two of the lobes of the noise-suppressing nozzle so that the latter can be adjusted to a reduced area to provide increased thrust at take-off, the area then being increased to reduce specific consumption and jet-pipe temperature during cruising flight. A typical engine of this series is the Mk 527 (Caravelle), full data for which are given beneath the line drawing on p. 394.

Early last year bench running began on the RA.29/5. This was largely a new engine, with an additional "zero-zero" compressor stage and air-cooled turbine blading; and the take-off rating of 13,300 lb was easily achieved on the bench, with a specific consumption below 0.7. Now, however, it is obvious that the completely new RB.141 is a preferable powerplant, and accordingly the 29/5 is not being proceeded with. Instead, Rolls-Royce have decided to offer the RA.29/6, which represents a fair limit to what can be done without changing the basic commercial Avon to any considerable degree. Rated at 12,500 lb, this engine incorporates the additional compressor stage together with other detail modifications, and can be produced by conversion of a 29/3 at a major overhaul.

Conway Rolls-Royce pioneered the by-pass principle, Dr. Griffith, the company's chief scientist, having been actively engaged in this field since 1945. Briefly, the by-pass principle consists of a two-spool turbojet in which the low-pressure compressor is of increased diameter and discharges air partly through the second (high-pressure) spool, combustion system and turbine, and partly through a by-pass duct surrounding the remainder of the engine. The two flows are then mixed in an optimum manner in a single jet-pipe which can be fitted with thrust reversal and a noise-suppressing nozzle.

Conway bench testing began in 1950 at the RCo.1 rating of 9,250 lb thrust. These early engines culminated with the type test of the RCo.5 at 13,000 lb dry in 1955 (at the time a record for both thrust and specific consumption for a type-tested engine). A progressive refinement and an increase in by-pass ratio then led to the current series of engines of the type depicted in the illustration. The RCo.10 has a guaranteed minimum dry thrust of 16,500 lb; last year it was type tested to the combined U.S./U.K. schedule at 17,000 lb and has A.R.B./F.A.A. approval at this figure. For the Boeing 707-436 *et seq*, Rolls-Royce supply the Mk 505 engine together with all engine accessories, firewalls, cowling, thrust reverser and noise-suppressing nozzle. These are shipped in knocked-down form to Seattle, where Boeing instal the Sundstrand drive, air (or fuel/air) starter and the turbo-compressor for cabin pressurization. The first complete set of Boeing pods was shipped in October. For the DC-8 Rolls-Royce supply the Mk 507 engine to Douglas as a bare unit, and the first delivery was made to Long Beach in October. Engines so far delivered to both companies have been 140 lb lighter than the guaranteed figure (which is classified) and have consistently been well inside the guaranteed specific consumption.

Identical in most major respects to the RCo.10 is the RCo.11 military engine, which has for some time been in production for the Handley Page Victor B.2. In December 1957 the RCo.11 was type tested at 17,250 lb dry.

Future commercial development will produce substantially increased powers. Initially the Mk 505 and 507 engines currently being delivered will be employed in service for a period of perhaps twelve months, following which an external modification to the control system will permit their re-calibration to the RCo.12 rating. This specifies a guaranteed minimum thrust of 17,500 lb, and engines have already been type tested to the U.S./U.K. schedule at 18,000 lb and have received type approval at this thrust. The next stage is an internal improvement to increase the mass flow, and this results in the RCo.15 guaranteed minimum rating of 18,500 lb dry. Considerably higher powers are in prospect.

Reference: Feb. 8, 1957 (by-pass principles).

Dart This single-shaft turboprop has been in airline service continuously for six years, and at the time of writing has recorded some 7,000,000 hr, almost entirely in Viscounts. The initial production engine, the RDa.3 Mk 506 of 1,400 s.h.p. (1,547 e.h.p.) has a scheduled overhaul life of 2,300 hr with B.E.A. and 2,000 hr with T.C.A. and should shortly surpass the longest overhaul life achieved by any piston engine.

Most of the engines currently in service are of the RDa.6 rating of 1,600 s.h.p. (1,742 e.h.p.), the most important of these units being the Mk 510 (Viscount) and Mk 511 (F.27 Friendship). Current production engines are largely of the RDa.7 rating which, according to application, varies from 1,800 to over 1,900 s.h.p. Typical examples of engines in this series are the Mk 525 (Viscount), 526 (AW.650), 527 (F.27 Friendship), 528 (Herald) and 529 (Gulfstream). An offshoot of this series is the Mk 21 rated at 2,100 e.h.p. which powers the Bréguet Alizé carrier-based ASW aircraft. This engine has a Dart RDa.6-size compressor, but employs the RDa.7's three-stage turbine, together with a 0.107:1 reduction gear matched to an 11ft 6in propeller.

Largely as a result of intense world-wide interest, Rolls-Royce have gone on to develop an up-rated Dart incorporating air-cooled turbine blading. The first of this series is the RDa.10, which is specified in the brochures of many projects throughout the world. As a result of its increased turbine inlet temperature, together with a redesigned compressor handling a greater mass flow, the RDa.10 has already passed a type test to the combined U.S./U.K. schedule at 2,400 s.h.p. dry (2,660 e.h.p.). This increased power is transmitted through a reduction gear with greater capacity to a propeller with blades of increased chord and a conical spinner similar to that of the Tyne. A related engine has already passed a 25-hr military type test at a wet rating of 3,200 s.h.p., giving an indication of the potential still available. An offshoot of this series is the RDa.11 Mk 541, in which the maximum power is restricted to 2,100 s.h.p. (2,350 e.h.p.) in order not to exceed the limitations imposed by the fin size of the Viscount.

References: Mar. 20, 1953 (history and description); Feb. 28, 1958 (RDa.7-10).

RB.108 Security precludes the publication of any details of this small turbojet of high thrust/weight ratio, apart from facts which can be deduced from an external inspection. Descended from the RB.82 Soar, the RB.108 is a single-shaft axial engine with a compressor of about five stages driven by a single-stage turbine, and with a high-intensity annular combustion chamber. Practically no accessories are carried on the engine, since in its normal rôle (the provision of vertical lift for the take-off and landing of VTOL aircraft) the RB.108 would be grouped in packages of perhaps a dozen engines all served by a common fuel pump and control system.

The current application of the RB.108 concerns the Short SC.1 experimental VTOL machine. In this aircraft one engine is mounted conventionally in the tail to provide forwards propulsion, and two pairs of lift engines are pivoted in a vertical position to provide lift and basic control in the hovering régime. The rated thrust of the RB.108 is 2,010 lb. Extensive development has taken place, and two complete sets of lift engines have been sent to Short Brothers and Harland Ltd. After initially flying as a conventional aeroplane on the power of the horizontally mounted RB.108, the SC.1 is now engaged in free hovering trials. It has already been propelled laterally by tilting the lift engines, and complete tran-

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sition to forward flight (with the lift engines inoperative) is imminent as we go to press.

RB.141 The Rolls-Royce company have unique experience in the commercial operation of turboprops and turbojets, and in the mass production of air-cooled turbine blading, the design and economics of by-pass engines and the evolution of lifed hot components. The RB.141 will be the first engine to incorporate all the lessons learnt, and the company's objective has been the simple one of designing and constructing the best possible engine for a high-subsonic jet transport. Starting with a clean sheet of paper Rolls-Royce have with this engine had utter freedom of choice, without being hamstrung with existing hardware or the need to meet the conflicting requirements of a variety of airlines and military services.

Little can be said about the engine at this stage, beyond that the thrust will range from 12,000 to 16,000 lb. It can, however, be stated that the ratio between the high-pressure and low-pressure pressure ratios has been so chosen as to permit the by-pass air and hot exhaust to issue with approximately equal energy. As a result the two flows can be mixed before expansion through the final nozzle without incurring severe losses, and the company have already published a drawing of the mixing nozzle (reference below). All calculations have been based on the performance of the complete installed powerplant, and development so far suggests that the company's great expectations will be more than realised. The engine has been chosen as the standard powerplant of the D.H.121 three-engined airliner for B.E.A., and the RB.141 will also admirably suit a developed Caravelle. A vast amount of rig running has been completed. Development was recently accelerated, and a complete unit should be running on the bench before the end of this year.

Reference: Oct. 24, 1958.

RB.145 The existence of this engine was revealed at the 1958 S.B.A.C. Display, when a mock-up was exhibited. Obviously derived from the RB.108, the 145 appears to be a high thrust/weight ratio turbojet for the propulsion of piloted aircraft, missiles and targets. In the form depicted it is fully equipped for the manned role, and should prove attractive for a wide range of aeroplanes. Compared with its predecessor it appears to have one or more additional compressor stages, and this no doubt helps to explain the increased rating.

Tyne Originally known by its development number of RB.109, the Tyne is a true second-generation turboprop in which is incorporated all the immense experience which Rolls-Royce have obtained with the Dart and with high-pressure, high-temperature military turbojets. Initially projected to have a rating of some 2,500 h.p., the Tyne today is in the 5,000 h.p. class and its development is expected to continue during the coming decade up to the region of 10,000 h.p.

From the outset Rolls-Royce determined to achieve the highest possible efficiency, and accordingly chose a high flame-temperature (made possible by the employment of air-cooled turbine blading) and a pressure ratio of 13:1 achieved by compression split between two spools. The propeller for the Tyne is a very advanced unit designed by de Havilland Propellers Ltd. The complete power package is the first in the British Commonwealth to incorporate β-control, in which propeller pitch is governed directly from the cockpit after selection of this regime. Considerable development has gone into the largely automatic system which controls the fuel flow and the propeller, and handling is now of an extremely high order. The Tyne is hung from four anti-vibration mounts on the rear face of the large oil tank surrounding the intake. In the centre of the intake is the two-stage reduction gear, and engine equipment includes an electric starter (pneumatic on the CL-44 powerplant) driving the high-pressure spool, together with several bleed manifolds, hot-air de-icing and a shaft-drive to a remote accessory gearbox.

The first bench-run took place on April 23, 1955. Flight development started in June 1956 with a Tyne mounted in the nose of a Lincoln and continued in the summer of last year with two engines mounted in an Airspeed Ambassador. A similar machine (actually a B.E.A. Elizabethan) is about to start intensive route flying with B.E.A. crews in order to prove the complete powerplant of the Vanguard. The first Vanguard has itself been flying since early this year.

First airline service is scheduled with B.E.A. for March 1960. These initial V.951 Vanguards will be fitted with the RTy.1 Mk 506 rated at 4,500 s.h.p. (4,985 e.h.p.). Succeeding Vanguards will have the second production engine, at the RTy.11 rating of 5,030 s.h.p. (5,525 e.h.p.). These Tynes incorporate several design improvements, including rematching to an even higher turbine entry temperature made possible by improved blade materials, and achieve a cruising s.f.c. of 0.388 lb/hr/e.h.p.. For the Canadair CL-44 the RTy.12 has a larger final nozzle in order to provide increased shaft-power at take-off, the propeller size being correspondingly increased. The RTy.12 has a military dry rating of 5,300 s.h.p. (5,730 e.h.p.) and is likely to enter service with the R.C.A.F. in the summer of next year. An essentially similar engine will be fitted to the Short SC.5 Britannic 3 for the R.A.F. and is also specified for NATO transport and maritime-patrol aircraft and for the twin-engined AW.651/661/671.

LRBM Engine Four years ago Rolls-Royce obtained a licence for the manufacture of large rocket motors incorporating features developed by the Rocketdyne Division of North American Aviation Inc. Rolls-Royce have been announced as the sub-contractor responsible for the propulsion of the British LRBM (long-range ballistic missile) Blue Streak. One might suppose that the engine concerned will have a chamber akin to that of the 150,000 lb-thrust S-3 (LR79) or MB-2 which power the American IRBMs, but Rolls-Royce are not yet permitted to divulge any details of the British-built engine. As previously noted, the company are, on behalf of the M.o.S., the managers of the rocket test site at Spadeadam Waste, Cumberland, where firings of Blue Streak engines will shortly commence.

AUSTRALIA

C.A.C. *Commonwealth Aircraft Corporation, Melbourne.* Notes on the history of engine production in Melbourne were given in our 1957 engine review. The plant is now engaged almost exclusively in the production and service support of turbojets of Rolls-Royce design.

Nene Between 1947 and 1954 a total of 114 engines designated Nene 2-VH was manufactured for the D.H. Australia Vampire Mk 30. These engines are rated at 5,000 lb thrust at 12,300 r.p.m. and are currently operated on a life of 350 hr between overhauls.

Avon Manufacture of Rolls-Royce Avons, basically to RA.3 standard, started in the winter of 1953-54. The original order was for 88 Avon Mk 1 engines of 6,500 lb thrust for installation in the Canberra B.20s of the R.A.A.F. This contract was later altered to 44 Avon Mk 1 and 47 Mk 109 engines, the latter being of RA.7 rating at 7,500 lb thrust. Simultaneously, tooling and production began on the fighter Avon Mk 20, also of 7,500 lb thrust, for installation in the CA.27 Sabre. Initially 82 engines to this standard were ordered, but 52 were delivered as Mk 20s and the remaining 30 were modified to Mk 26 standard with improved handling characteristics. A Mk 26 recently completed a 150 hr type test, chiefly to confirm the suitability of locally produced materials and certain design features. All Mk 20s will eventually be modified to Mk 26 standard. Extension contracts totalling 36 additional Avon 26s were received last year, and this will bring the total of engines for Sabres to 127. Of these, 91 had been delivered by the end of January.

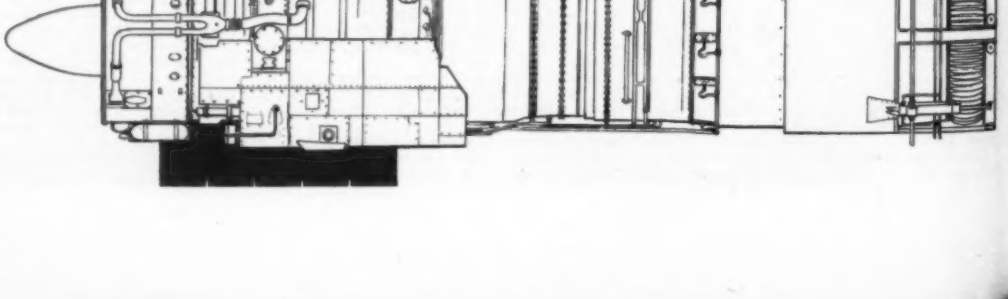
CANADA

ORENDA *Orenda Engines, Ltd., Toronto.* During the past decade this company have built up a large and capable design, development and production organization completely from scratch. The Orenda turbojet has been built in large numbers and is today in service in several countries; the Iroquois, one of the most powerful supersonic turbojets in the world, has been brought to an advanced state of development. As these words are written, however, it appears that the company's activities must be substantially curtailed in view of the cancellation of the only application of the Iroquois and the cessation of production of the Orenda. The position has yet to be clarified.

Orenda Production of the single-shaft Orenda has now virtually ceased, with a total of some 3,000 engines delivered. The final production versions were the Orenda 11 (7,500 lb thrust for the CF-100 Mk 5) and the Orenda 14 (7,500 lb thrust for the Sabre 6). Considerable development had also taken place on the Orenda 11R, equipped with Bristol simplified reheat and a Marquardt two-position nozzle; this engine was intended for the CF-100 Mk 6 and was rated at 8,250 lb.

Iroquois Six years ago the R.C.A.F. concluded that they would require an advanced all-weather fighter to succeed the CF-100, and Orenda Engines (then the engine division of A. V. Roe Canada) initiated the development of the most powerful turbojet in the British Commonwealth. Originally designated P.S.13, it was later named Iroquois and was evolved

Orenda Engines Iroquois 2 Military two-spool turbojet. Split axial compressors with a total of ten stages, high-velocity annular combustion chamber with 32 upstream-injection vaporizing burners, single-stage h-p. turbine, two-stage l-p. turbine, close-coupled afterburner with 60 nozzles and fully modulated con-di nozzle. Basic engine diameter, 42in; max diameter across afterburner, 47in; overall length, cold, 231in; dry weight, including afterburner and nozzle but excluding starter and firewall, 4,650 lb; max dry rating, over 20,000 lb (probably about 22,000); max thrust with reheat, about 30,000 lb; corresponding mass flow, about 420 lb/sec; pressure ratio, 8:1; specific fuel consumption, about 0.85 dry, 1.9 with reheat.



in parallel with the aircraft, which became the Avro CF-105 Arrow Mk 2.

Design began in September 1953. Subsequent progress was as follows: first drawings issued, January 1954; design completed, May 1954; first light-up achieved, December 15, 1954; 50 hr pre-flight rating test, June 24, 1956; first afterburner light-up, July 3, 1956; 1,000 hr of bench running completed, September 19, 1956; cold-weather testing started at N.R.C., February 15, 1957; first engine shipped to N.A.C.A. (N.A.S.A.) for high-altitude testing, April 22, 1957; first official 100 hr test completed, July 27, 1957; demonstration run completed at over 20,000 lb for both dry and afterburner ratings, November 1, 1957; first in-flight light-up achieved with engine installed in B-47, November 13, 1957; first engine delivered to Avro Aircraft, late 1958.

Although designed for flight Mach numbers far in excess of 2, and having a total of only ten compressor stages with a design pressure ratio of 8:1, the Iroquois is a two-spool engine. Very extensive development led to the evolution of advanced designs of combusion chamber and afterburner and all the main bearings run appreciably cooler than the air surrounding them. Engine equipment includes Lucas-Rotax air-turbine driven fuel pumps and hydromechanical controls, a pair of shunter surface-gap igniters and an AiResearch pneumatic starter. The oil tank has a capacity of 40 pt, the maximum consumption being 3 pt/hr. In the Arrow there are no transverse firewalls; the airflow around the engine is supersonic and the accessories are accordingly protected by being boxed in beneath the compressor casing. The front end of the engine is de-iced by compressor-bleed air.

At present the future of the engine is in jeopardy, since the government contract against which it was being developed was cancelled last month. At that time more than 7,200 hr had been run, including 141 hr at the N.A.S.A. Lewis Flight Propulsion Laboratory and 154 hr (including 23 hr afterburning) at the Arnold Engineering Development Center. A total of 31 hr flight testing had been accomplished at Malton with engines installed on the starboard side of the rear fuselage of a B-47. The engine had not been flown in the Arrow Mk 2.

BELGIUM

F.N. *Fabrique Nationale d'Armes de Guerre, Herstal.* After delivering more than 1,000 Rolls-Royce Derwents to power the Gloster Meteors jointly manufactured in Belgium and Holland, this famous armaments company have manufactured some hundreds of Rolls-Royce Avons for the Benelux-produced Hawker Hunters. The bulk of the engines delivered have been of the 100 series, but for at least eighteen months production has been centred on the 200-series engines used in the Hunter 6.

CZECHOSLOVAKIA

OMNIPOL *Omnipol, Prague 3, Washingtonova 11 (National agency for aero-engines).* Production is continuing upon the well-known Walter Minor 4-III, which was described and illustrated in our review of April 9, 1954. Small numbers of the six-cylinder Walter Minor 6-III are also being delivered. Both these are inverted in-line air-cooled piston engines rated at 105 and 160 h.p. respectively. When development is completed, these engines are likely to be succeeded respectively by the M-332 140 h.p. inverted four-in-line and M-337 inverted six-cylinder engine rated at 200 h.p. Both these new engines employ direct fuel injection.

During the past five years the Praga Doris B has been fully developed, and it is now in production and wide service as the powerplant of the L.60 Brigadyr multi-purpose aircraft. An air-cooled flat-six with a geared drive, the current Doris M-208B has a swept volume of 437.33 cu in, a dry weight of 435.6 lb and a maximum rating of 220 h.p. at 3,000 r.p.m. with a propeller speed of 1,655 r.p.m.

It is not yet known whether or not any recent Russian gas turbines are being manufactured in Czechoslovakia, but for at least three years the ASh-82 fourteen-cylinder radial has been manufactured for the Avia 14 (Il-14 derivative) family of twin-engine transports.

FRANCE

DASSAULT *Avions Marcel Dassault, 78 Quai Carnot, Saint-Cloud.* In our July 26, 1957, issue we related the manner in which this large airframe manufacturer obtained a licence from Armstrong Siddeley Motors for the Viper turbojet and proceeded to build a small number for use in such aircraft as the Sud Trident II and Dassault Mirage I. The latter aircraft has completed a substantial amount of development flying powered by twin M.D.30Rs fitted with reheat, and—like the Trident—has exceeded a Mach number of 2 with the Vipers running. The French Viper corresponds approximately to the ASV.3/ASV.5, being rated at 1,630 lb dry and 2,200 with reheat.

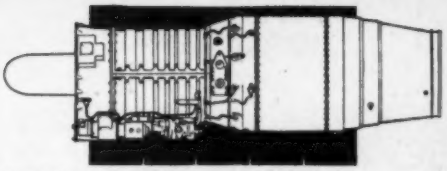
R.7 Farandole The first engine of Dassault design, the R.7 is virtually a Viper ASV.10 scaled up to a linear ratio of 1.3:1. Like the British engine, it is initially very cool running and should have appreciable growth potential. The first of several prototypes began bench trials in December 1956, and development has been satisfactory although it is not yet known whether the engine has flown. In addition to the version described beneath the drawing an afterburning variant is also under development for flight at Mach numbers of approximately 2. The basic Farandole is visualized as the powerplant of the projected Dassault Méditerranée light transport.

DRUINE *Avions Roger Druine, Paris 16.* Basing his work on the standard Porsche/Volkswagen air-cooled flat-four, the late M. Druine developed a powerplant for his Turbulent light aircraft under the name of Arden 4 CO2. On 80 octane fuel, this engine has a rated take-off power of 30.7 h.p. at 3,000 r.p.m. and weighs 133 lb complete with propeller and accessories. Rollason Aircraft and Engines are making this powerplant at Croydon.

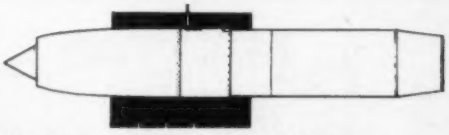
HISPANO-SUIZA *Société d'Exploitation des Matérials Hispano-Suiza, Rue du Capitaine Guynemer, Bois-Colombes, Seine.* In our last engine review issue we suggested that this famous company could feel that they had received a raw deal from the French Government. In the development and mass-production of centrifugal turbojets of basically Rolls-Royce design, Hispano-Suiza performed an outstanding job, and four years ago they had delivered every French turbojet then in service with the French Air Force. Some 1,600 engines were delivered, the last (and most numerous) version being the Verdon 350 rated at 7,710 lb dry. Production has now virtually come to an end, and the company's own R.804/854 axial turbojet of 3,300 lb thrust (4,500 lb with reheat) has not found an application.

NORD *Nord-Aviation SNCA, Paris 7.* This famous French company and its predecessors have been engaged in the development of subsonic and supersonic ramjets for several years past. This work has been reported in our previous engine reviews of April 9, 1954; May 11, 1956; and July 26, 1957. Current work is centred largely upon the turbo/ramjet Griffon aircraft and the self-contained supersonic ramjet Sirius I.

Griffon Development of the Griffon series of supersonic research aircraft is continuing under a research contract from the French Government. Flight testing of the Griffon 01 has been most successful, and in the course of some 200 flights speeds in excess of Mach 2 have been surpassed at altitude and high accelerations at this speed have been recorded with a relatively low fuel feed to the ramjet portion of the powerplant. At 59,000ft in level flight it has been found that the Atar E3 without reheat in conjunction with slight augmentation from the ramjet portion of the Griffon produces thrust appreciably superior to that from an Atar G with reheat. The intake is a direct pitot, the efficiency of which is improved by the presence of an oblique shock; the propelling nozzle is a fixed-geometry convergent assembly. Maximum diameter of the ramjet duct is 59in and the total weight of the propulsion system is 3,748 lb.



Dassault R.7 Farandole Commercial single-shaft turbojet. Seven-stage compressor, annular combustion chamber with vaporizing burners and single-stage turbine. Overall diameter across combustion chamber, 28.75in; overall length as depicted, 99in; equipped dry weight, 750 lb; max dry rating, 3,100 lb at 11,800 r.p.m. with s.f.c. of 1.07 and mass flow and pressure ratio of 55 lb/sec and 3.8:1.



Nord-Aviation Sirius I Ramjet with fixed-geometry double-shock intake and convergent nozzle. External diameter, 25.4in; overall length as depicted, 165.35in; dry weight, 313 lb, of which 48.5 lb is accounted for by the fuel system; design Mach number 2.4.

Sirius I The first supersonic ramjet to be developed by Nord, the Sirius is intended for the cruise propulsion of missiles or for the auxiliary propulsion of aircraft intended to hold Mach numbers between 1.5 and 2.5 for periods of at least 15 min. The configuration of the unit has been planned to facilitate its application to a wide range of flight vehicles; the attachment points consist simply of a front trunnion, and a main anchorage close to the centre of gravity through which pass the fuel and electric lines. The fuel-pump group and control system are housed entirely within the intake centre-body, and the propelling nozzle is of simple convergent fixed-geometry form. The main application of the Sirius I will be the propulsion of the Nord-Aviation CT.41 target.

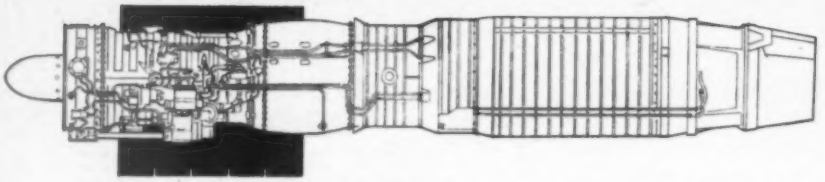
Nord are at present investigating a variety of advanced ramjets both for missile propulsion and as auxiliary aircraft power units. Results have been obtained at real and simulated altitudes of the order of 82,000ft at Mach numbers in excess of 3.5.

POTEZ *Société des Avions et Moteurs Henry Potez, 46 Avenue Kléber, Paris 16.* Most small French piston-engined aircraft use American powerplants, but Potez have assured business with the 240 h.p. 4-D 30 supercharged inverted four-in-line which has been adopted as the standard powerplant of the Nord 3400 Army A.O.P. aircraft.

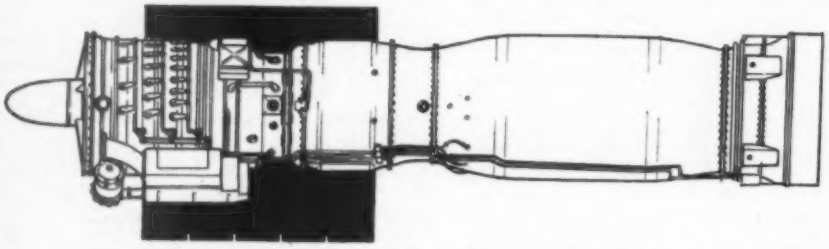
S.E.P.R. *Société d'Etude de la Propulsion par Réaction, 37 Rue des Acacias, Paris.* Since 1947 this company have specialized in all forms of rocket propulsion, concentrating particularly upon solid-propulsion boost motors and missile powerplants and upon liquid-propellant engines running on nitric acid and furfuryl alcohol. In our July 26, 1957, issue we reported extensively upon the work of S.E.P.R. and described the manner in which they introduce a liquid inhibitor to the acid to permit propulsion systems to be stored in immediate readiness.

A wide range of aircraft engines has been developed and flown, but the production applications have vanished one by one until it now appears likely that the only aircraft of the immediate future likely to see service with an S.E.P.R. unit is the Dassault Mirage III. This aircraft will have the latest of the company's aircraft rocket engines, the single-chamber S.E.P.R. 84 rated at 3,307 lb thrust at sea level. No details of this unit are available, but it undoubtedly incorporates a turbopump to feed the propellants from remote tankage. Previous S.E.P.R. motors have been fixed-thrust units.

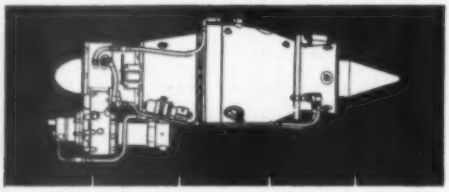
SNECMA *Société Nationale d'Etude et de Construction de Moteurs d'Aviation, Paris 8.* As the largest firm on the European continent devoted exclusively to the propulsion of aircraft, SNECMA have since 1945 manufactured some thousands of engines. Piston engines placed in bulk production have included the Regnier 4L series of inverted four-in-lines (140 h.p.), the 12S and 12T inverted vee-12s



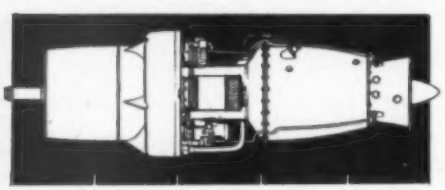
Snecma Atar 9. Military single-shaft turbojet with afterburner. Nine-stage compressor, annular combustion chamber with 20 burners in individual cups, two-stage turbine and variable-augmentation afterburner with three-position nozzle. Max diameter over turbine casing, 33.86in; overall length as depicted, 263.8in; dry weight, 2,755 lb; max ratings, 13,228 lb at 8,400 r.p.m. with full reheat (s.f.c. 2.075), 11,905 lb with partial reheat (s.f.c. 1.7) or 9,370 lb dry (s.f.c. 1.1), with mass flow and pressure ratio of 149.9 lb/sec and 5.5:1. The Atar 8, without afterburner, weighs 2,028 lb and is rated at 9,700 lb dry with s.f.c. of 0.98.



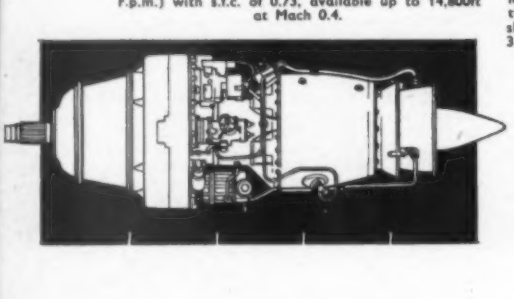
SNECMA Super Atar (provisional drawing). Military single-shaft turbojet. Axial compressor with about five stages, with variable-incidence inlet guide vanes and first two stators, annular combustion chamber, two-stage turbine and large afterburner with fully variable convergent/divergent nozzle. Overall diameter at intake, 37in; approximate overall length as depicted, 210in; dry weight, probably about 3,700 lb; max rating, about 22,000 lb with reheat with mass flow and pressure ratio of about 325 lb/sec and 6:1.



Turboméca Arbizon. Single-shaft turbojet. Single transonic axial compressor stage followed by single centrifugal stage, annular combustion chamber and two-stage turbine. Overall height, 19.9in; overall width, 16.4in; dry weight, 230 lb; max thrust, 550 lb at 34,000 r.p.m. with s.f.c. of 0.92 (max cont., 440 lb).



Turboméca Astazou. Single-shaft turboprop. Single transonic axial compressor stage followed by single centrifugal stage, annular combustion chamber and multi-stage turbine. Overall diameter, 18.1in; length as shown, about 69in; dry weight, 245 lb; mass flow and pressure ratio, not available; max rating, 320 h.p. at unstated r.p.m. with s.f.c. of 0.72 (this power is limited by reduction-gear capacity and is available up to 92 deg F, or up to a height of 15,000ft at Mach 0.45).



Turboméca Bastan. Single-shaft turboprop. Single transonic axial compressor stage followed by single centrifugal stage, annular combustion chamber and multi-stage turbine. Overall diameter, 21.6in; length as depicted, 60.9in; dry weight, with propeller but without oil-cooler, 585 lb, or 397 lb without propeller; mass flow and pressure ratio, not available; max rating, 650 s.h.p. at 33,000 r.p.m. (1,790 propeller r.p.m.) with s.f.c. of 0.73, available up to 14,800ft at Mach 0.4.

AERO ENGINES 1959 . . .

(600-625 h.p.) and, under Bristol licence, the Hercules 759 radial (2,040 h.p.). The major development and production has centred upon the Atar family of single-shaft turbojets. The latter, and the new Super Atar, are commented upon below.

Atar A brief history of this simple and reliable axial engine was given in our July 26, 1957, issue. The first version to enter production, in 1953, was the Atar 101 D-1, rated at 6,610 lb dry and used in the Mystère II (France, India and Israel). The 101 E, of 7,716 lb rating, has been made in great numbers for the Sud Vatour and for such machines as the Baroudeur, Griffon, Leduc O.22 and, in a special form, the Atar Volant. Some hundreds of Atar 101 G-series engines have followed, rated at 9,700 lb with reheat, for the Dassault Super Mystère B.2, and for various other high-speed aircraft. The Atar D had a seven-stage compressor, but a zero-stage was added in the E and retained in the G. A further "zero-zero" stage, together with a second turbine stage, were added in the next series, the Atar 8 and 9.

These new Atars are virtually completely redesigned, and give very much higher thrust up to Mach numbers well beyond unity. The new compressor, which operates at a pressure ratio of 5.5 (compared with 4.8 of the earlier Atar E/G), has 1,335 blades, those of stages 2 to 6 (rotor) or 3 to 6 (stator) being of light alloy and the remainder being steel. The Atar 8, the first of the revised engines, weighs 2,180 lb, has a dry rating of 9,700 lb with s.f.c. of 0.98, and is in production as the powerplant of the Dassault Etendard IV M carrier-based fighters. The Atar 9, illustrated, powers the Dassault Mirage IIIA and has already flown at more than Mach 2.2.

Super Atar At present this engine remains largely shrouded in secrecy, since it is necessarily being developed to a fairly long-term time scale. Although bearing the name Atar it is doubtful if it incorporates any components of the earlier Atars, and from a variety of sources it is possible to assess it as a very advanced unit indeed. Bearing in mind its announced applications in the Mach range above M 3, it is hardly surprising to find that SNECMA have lowered the pressure ratio, introduced variable-incidence blading in the inlet guide vanes and first two rows of stators, and switched to steel as the ruling structural material. Notwithstanding the latter fact, however, the weight has been held at a value not much in excess of the latest Atars of half the thrust. Most of the data which may be quoted are given with the drawing; it is not surprising to find that, like Orenda Engines with the Iroquois, the fuel and control systems are housed in a cooled box, and special measures are being taken to prevent bearing temperatures from becoming excessive.

It is known that portions of the Super Atar have been undergoing rig-testing at Melun-Villaroche, but no information is forthcoming upon the progress of the complete engine. The mere existence of the Super Atar as a firm project in itself is a matter of very great interest. It remains to be seen whether its development will be allowed to continue, or whether—like its counterparts in all other Western nations except the U.S.A.—it will fail to find a production application.

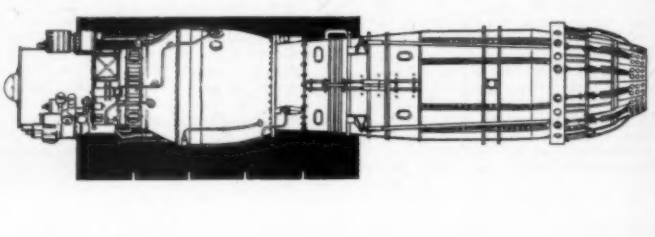
TURBOMECA *Société Anonyme Turboméca, Bordes (Basses-Pyrénées).* The list of small gas turbines produced by this private company located in the Pyrenees foothills has now reached alarming proportions; fourteen of the most common recent types were described in some detail in our last engine review issue and a smaller number are dealt with here. By far the most important engine has always been the Marboré turbojet, which has been in bulk production at Bordes for four years and is being manufactured under licence in several countries, as noted below. All the first families of Turboméca engines employ simple single-sided centrifugal compressors, but in 1955 a new family of more efficient units was produced in which the pressure ratio was increased by the addition of a high-speed axial stage upstream of the centrifugal impeller. The most important of this new family are probably the Turmo III turboshaft engine for helicopters and the Bastan fixed-wing turboprop.

Artouste Some 300 of these single-shaft engines have been delivered, chiefly to power the Sud Alouette II helicopter. The standard Alouette engine is rated at 360 h.p. at 5,780 output r.p.m. (33,000 turbine r.p.m.) with a consumption of 335 lb/hr. The Artouste IIB1 was awarded a C.A.A. type certificate in January last year and, uprated by Continental to 425 h.p. are being supplied via the American company to power the Republic-assembled Alouette helicopters. Turboméca are continuing development of the uprated Artouste III, which has a maximum power of 550 h.p. and (further uprated to 600 h.p.) can be provided with a drive for coaxial propellers.

Astazou First revealed at the 1957 Paris Salon, this very neat single-shaft turboprop has completed a considerable amount of bench running, including pre-flight rating tests. It has a number of projected applications, and is being installed in a Broussard.

Bastan Probably the most important of the company's current range of new engines, the Bastan has completed well over 1,000 bench hours and has started flying as the powerplant of the Beech Super 18 test bed purchased by

Turboméca Gabizo. Single-shaft turbojet with afterburner. Single transonic axial compressor stage followed by single centrifugal stage, annular combustion chamber, single-stage turbine, and afterburner with two-position nozzle. Overall diameter (on reheat pipe), 26.77in; intake diameter, 17.7in; overall length as shown, 142.2in; dry weight, about 740 lb; mass flow, about 45 lb/sec; pressure ratio, about 5:1; max thrust, 3,396 lb at 17,500 r.p.m. with s.f.c. of 2.25. Basic engine weighs 585 lb, has rating of 2,420 lb with s.f.c. of 105.



Turboméca for the purpose. As the illustration shows, the engine is of very neat layout; the accessories are disposed around the compressor casing, being driven by a train of spur gears from the front of the main rotating assembly. At the front, mounted centrally within the annular intake, is the two-stage reduction gear which drives a three-blade, constant-speed propeller, usually with a diameter of 9ft 3in, the pressure oil for which is tapped from the engine system. Compressed air can be bled from the main diffuser, and a 15 h.p. mechanical drive can serve a remote gearbox. The Bastan has been chosen as the standard powerplant of the Dassault M.D.415, Max Holste M.H.260 Super Broussard, Morane Saulnier M.S.1500 Epervier and Sud 116 Voltigeur.

Gabizo The largest engine yet produced by Turboméca, this turbojet was one of the first engines to employ the upstream axial stage on the compressor. Fitted with a Nord afterburner and two-position nozzle, it was intended to power the family of twin-engined NATO light attack aircraft which represent the French formula in competition with the successful NATO choice of a single Bristol Orpheus. The engine has flown in at least eight types of aircraft but has no production application at present.

Marboré Described briefly in the section dealing with Continental (U.S.A.) this turbojet is the standard powerplant of the twin-engined Magister and Esquif basic trainers, and a special low-cost version is employed in the Nord CT-20 target. Most of the Marborés in service employ an improved combustion chamber (a scaled version of the Gabizo chamber) which reduces the pressure drop and slightly increases the thrust. A typical Marboré II weighs 320 lb unequipped, and has a maximum rating of 880 lb. The Marboré IIC was awarded a C.A.A. type certificate on June 10 last year and is licence-produced by Continental as previously noted; similar powerplants are also being manufactured in Western Germany and production licences are held by Spain and Yugoslavia.

Marcadau This name denotes the Artouste II turboshaft engine fitted with a reduction gear of 2.332:1 ratio providing a drive suitable for a fixed-wing turboprop application. The engine was briefly described in our 1956 engine review and has recently been powering the first prototype M.S.1500 Epervier.

Palouste IV A direct development of the well-known earlier series of Palouste air compressors, the Palouste IV has a maximum delivery of 2.5 lb/sec at a pressure ratio of 3.75:1 and has been built in some numbers as the powerplant of the Sud 1221 Djinn tip-drive helicopter.

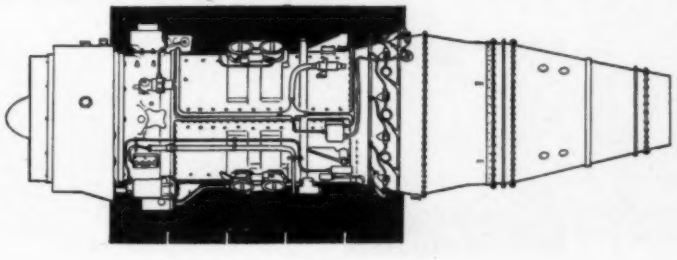
Turmo Turboméca's first free-turbine engine, the Turmo has appeared in three major versions. The Turmo I and II, respectively rated at maximum outputs of 270 and 400 s.h.p., have not found wide application in France, but the Turmo III illustrated here is the powerplant of the Sud 3200 Super Alouette transport helicopter. This large single-rotor machine is powered by three Turmo IIIs with their output shafts all geared to a common reduction gearbox in order to provide a flexible and efficient drive capable of maintaining safe flight with one engine out of action.

GERMANY

East Germany

LIKE all other strategic industry in East Germany, the design, development and production of aero engines is handled by a national organization. Aircraft engines are developed and manufactured at Chemitz, under the direction of the Verwaltung der Luftfahrtindustrie. Production at Chemitz initially centred upon the ASh-82 fourteen-cylinder piston engine of Soviet design, and at least 100 of these have been delivered to power the Il-14 transports manufactured by the VEB at Dresden. During the past five years the original Junkers Jumo 012 turobjet design has been taken over from the Soviet Union and developed into the engine described below. The latter is the first gas turbine to have been produced in Germany since 1945, and is at present flying as the powerplant of the Type 152 transport.

Type 014 A neat single-shaft engine, this turbojet has been designed for long life, reliability and low cruising specific consumption. As far as possible, therefore, it incorporates parts already developed during Soviet work on the Jumo 012, and avoids the use of variable compressor stators, air-cooled turbine blades or any other techniques which could give rise to severe development problems. The pressure ratio is reasonably high and four pairs of blow-off valves are arranged around the casing to ease handling during the starting cycle and acceleration. Equipment includes an electric starter mounted in the intake bullet and an annular oil tank surrounding the air-intake casting. The combustion chamber is served by twelve downstream burners each mounted at the centre of a conical flame tube, the twelve flame tubes quickly merging and leading into a truly annular combustion chamber fabricated from Nimonic-like material. It appears likely that the engine will be made in some numbers as the powerplant of the Type 152 and Type 153 civil transports, and it has been suggested that developed versions will shortly make their appearance.



Type 014 Commercial single-shaft turbojet. Twelve-stage compressor, annular combustion chamber with 12 flame tubes which merge to form truly annular space, two-stage turbine. Overall maximum carcase diameter, 38.58in; overall length as depicted, 161.5in; dry weight, approximately 2,200 lb; max rating, 6,945 lb with s.f.c. of 0.85 and mass flow of 110 lb/sec.

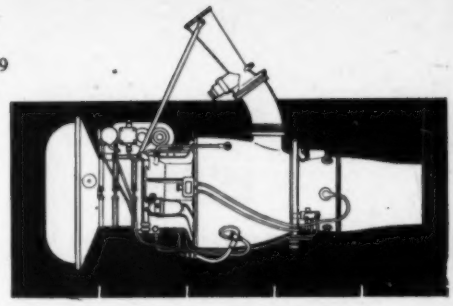
West Germany

BMW *BMW Triebwerkbau Gesellschaft M.B.H., Munich, 68.* In November 1957 BMW concluded a licence agreement with the Lycoming Division of Avco in respect of the GO-480-B1A6 flat-six piston engine. Some hundreds of engines have already been manufactured, chiefly for the Dornier Do 27 and Focke Wulf/Piaggio P.149D. BMW also hold a licence to manufacture the Bristol Siddeley Orpheus, and undertake major repairs and overhauls on Orenda 10 and 14 turbojets for the Luftwaffe.

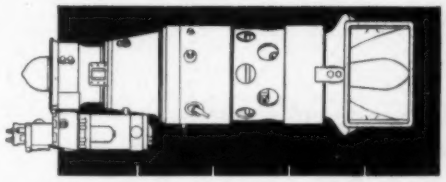
HEINKEL *Ernst Heinkel A.G., Stuttgart-Zuffenhausen.* As heirs of the former Ernst Heinkel Flugzeugwerke, which built the He S 3B turbojet, the first gas turbine ever to fly, Ernst Heinkel A.G. have reorganized their plant in Stuttgart, and in addition to substantial work in the industrial and automotive fields are engaged in the servicing and repair of Turboméca Marboré II turbojets for the Luftwaffe and in the development of a large turbojet of their own design. This engine, the He S 053, is apparently a company-sponsored venture, although it is clearly on such a scale that government funds will have to be injected before long.

He S 053 The intake is cast in aluminium alloy, has de-icing by compressor-bleed air and houses 48 variable-incidence steel inlet guide vanes. The compressor stator comprises a six-stage low-pressure section fabricated in aluminium alloy and a five-stage high-pressure section entirely made in steel. The compressor rotor is of steel, and carries four l-p rows of aluminium-alloy blades and seven h.p. rows of steel blades.

In order to provide optimum performance over the entire range of flight conditions, the engine has a variable-area nozzle with two clamshell shutters. A hydromechanical control system is fitted, providing single-lever master control, automatic starting and acceleration,



Turboméca Palouste IV. Air compressor. Single centrifugal compressor, annular combustion chamber and two-stage turbine. Overall height as depicted, about 34in; width, about 21.6in; overall length, 52.3in; dry weight, 198 lb; pressure ratio, 3.7:1; max output, 2.51 lb/sec of air at 41.2 lb/sq in gauge at 34,000 r.p.m. with fuel consumption of 265 lb/hr; max cont., 2.4 lb/sec.



Turboméca Turmo III. Free-turbine engine. Single transonic axial compressor stage followed by single centrifugal stage, annular combustion chamber, two-stage compressor turbine and independent single-stage power turbine. Overall width, 29.4in; overall height, 22.25in; overall length 65.6in; dry weight, 530 lb; mass flow, about 10.6 lb/sec; pressure ratio, about 5.1:1; max rating, 750 h.p. at 34,500 r.p.m. (6,000 output r.p.m.) with s.f.c. of 0.77. A take-off rating of 900 h.p. with a max overload of 1,000 h.p. is foreseen for the near future.

and integrated governing of r.p.m., j.p.t. and exhaust nozzle area. Heinkel have done the fuel system themselves, there being a gear-type fuel pump delivering at 570 lb/sq in, a flow control with altitude compensator and nine main Duplex burners, two of which are ignited at starting by a high-energy ignition system. An electric starter is employed, and the lubrication system includes a single pressure pump and three scavenge pumps serving a closed-circuit incorporating a saddle-type tank and an air/oil cooler. The data given beneath the drawing are provided by the manufacturer; it is also stated that an afterburning version is being developed with a maximum reheat rating of 19,800 lb for a total powerplant weight of 4,354 lb. It has been stated unofficially that at least one engine is at present undergoing bench testing; certainly some rig running of components has been undertaken.

PORSCHE *Dr.-Ing. h.c. F. Porsche K.-G., Stuttgart-Zuffenhausen.* A considerable number of aero-engine derivatives of Dr. Porsche's well-known air-cooled flat-four are now in use. The three standard versions are designated 678/0, 678/1, and 678/3. All are basically similar, with a swept volume of 96.5 cu in. The /0 weighs 192 lb, has a reduction gear with a ratio of 1.7:1, twin carburettors, a take-off output of 65 h.p. at 4,500 r.p.m. and an economical cruising output of 50 h.p. The /1 has a single carburettor and a different reduction gear ratio, and has successfully completed a 150-hr type test to A.R.B. requirements. The /3 is an ungeared version weighing 154 lb, with ratings of 52 h.p. at 3,200 r.p.m. and 40 h.p. at 2,950 r.p.m.

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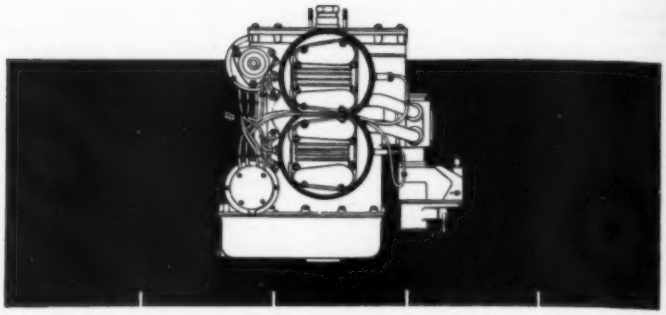
INDIA

Hindustan Aircraft at Bangalore have built a new plant in order to manufacture the Orpheus turbojet under licence from Bristol Siddeley. The factory is fully tooled, personnel are being trained and assembly of Bristol-made parts and manufacture of Hindustan parts is in hand. The Orpheus 701 is the first product, and the BOr.12SR may follow.

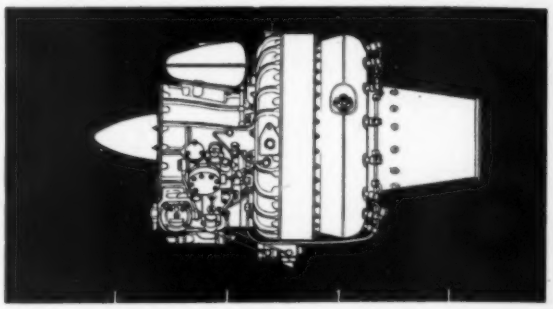
ITALY

AGUSTA *Meccanica Verghera Agusta, Gallarate (Prov. Varese).* This prosperous and versatile company are in limited production with three types of light air-cooled horizontally opposed piston engines. The smallest is a flat-twin rated at 42 h.p., and the four-cylinder engines comprise a geared fixed-wing unit rated at 83 h.p. and a vertical-crankshaft helicopter engine rated at 82 h.p. One of these is described and illustrated here; all were dealt with in our July 26, 1957, issue.



Agusta G.A.70/V. Piston engine for helicopters. Horizontally opposed four-cylinder engine mounted with crankshaft vertical, with float-chamber carburettor, dual ignition and electric starter; gearbox or fan not shown. Overall width, 28.9in; height as shown, 22.8in; length, front to rear over carburettor, 21.25in; swept volume, 140.4 cu in; dry weight, 147.7 lb; max rating, 72 h.p. at 3,100 r.p.m. at engine shaft.

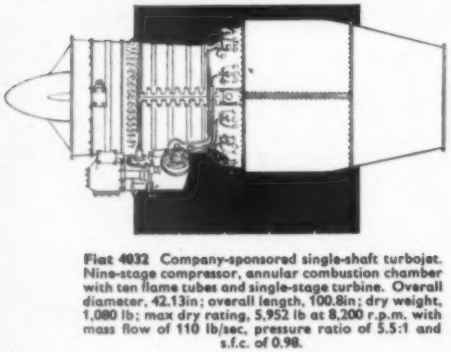
FIAT *Fiat S.p.A., Divisione Aviazione, Corso G. Agnelli, 200, Turin.* During the past 51 years this immense and renowned company has designed and manufactured 54 types of aero engines. Reconstructed after 1945, the great plant at Lingotto worked on the manufacture and overhaul of Goblin and Ghost turbojets under licence from D.H. Engines, and upon the overhaul of Allison J35s, General Electric J47s, Wright J65s and a wide range of piston engines. The company is also, under Bristol Siddeley licence, preparing to mass-produce the Orpheus turbojet. Fiat have now returned to the development of their own engines, and the following gas turbines are their most important current projects.



Fiat 4002.001 Company-sponsored turbojet. Centrifugal compressor, annular combustion chamber with 16 burners and single-stage turbine. Overall diameter, 22.5in; overall length, 32.6 in; dry weight, 194 lb; max rating, 716.5 lb thrust at 25,000 r.p.m. with mass flow of 13.23 lb/sec, pressure ratio of about 4:1 and s.f.c. of 1.21.

4002 A description of this attractive small turbojet appeared on p. 127 of our July 26, 1957, issue. The first Fiat-designed gas turbine, it is intended to offer reliable and trouble-free operation in the most arduous conditions, and is being evolved in both civil and military forms. The current version is described and illustrated; it was preceded by the 4002.000, which was rated at 595 lb thrust, weighed 220 lb and was described in our 1956 engine review.

4032 The first axial engine to be designed by Fiat, the 4032 is intended as a competitor for the propulsion of advanced versions of the G.91 and other NATO aircraft currently powered by the Orpheus. The engine is bigger than the Orpheus and, although intended initially for purely military applications, should be capable of an appreciable amount of growth beyond the existing design points. Noteworthy features include the elimination of a centre bearing, and partial overlapping of the central diffuser section by the front end of the combustion chamber, the latter being of the partial inwards reverse-flow type employed in the 4002 (although the fuel manifold is at the front). The intake is cast in magnesium-zirconium alloy, and the engine is equipped with a hydromechanical control system which provides automatic starting and acceleration from a single cockpit lever. This engine is still in the preliminary stage of development and has yet to undergo bench tests.



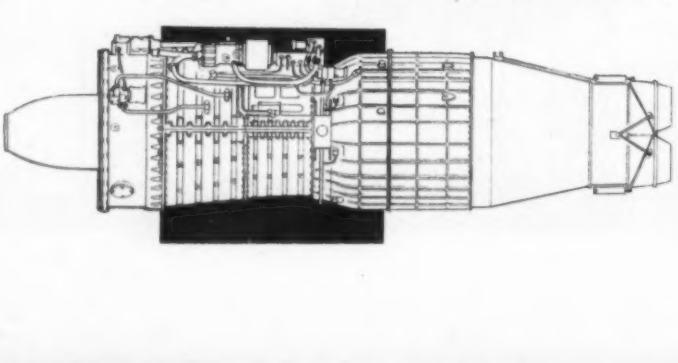
Fiat 4032 Company-sponsored single-shaft turbojet. Nine-stage compressor, annular combustion chamber with ten flame tubes and single-stage turbine. Overall diameter, 42.13in; overall length, 100.8in; dry weight, 1,080 lb; max dry rating, 5,952 lb at 8,200 r.p.m. with mass flow of 110 lb/sec, pressure ratio of 5.5:1 and s.f.c. of 0.98.

4700 Intended to supply air to helicopter cold tip-drive units, the 4700 is a gas turbine compressor set making maximum use of components already developed for the Fiat 4002 turbojet. In order to minimize the length of ducting between the engine delivery connection and the rotor hub, the 4700 is designed for vertical mounting, with the intake at the lower end. The latter is a magnesium-zirconium casting with seven radial spokes, through which the air is drawn inwards and upwards to the eye of the centrifugal compressor, which is machined in aluminium alloy with 22 vanes. After passing through a twelve-vane diffuser the air is straightened by a row of steel blades and enters the combustion chamber. The design of this unit follows closely upon that of the 4002, being of the annular type with a considerable degree of inwards reverse flow.

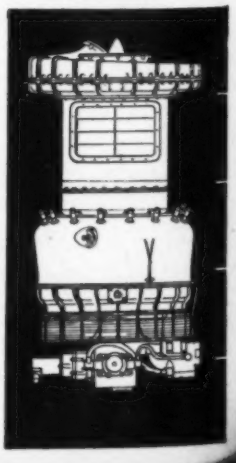
From the combustion chamber the hot gas is directed between a row of welded-sheet stators on to the single-stage compressor turbine. The latter comprises a disc of heat-resistant steel into which are inserted blades of cobalt alloy; the compressor drive-shaft is hollow and is attached by stud bolts at either end, the complete rotating assembly being supported by a ball thrust bearing beneath (i.e., upstream of) the compressor and a roller bearing immediately beneath the turbine disc. From the compressor turbine the gas passes upwards through a second row of stators to the free power turbine, and then leaves the engine horizontally through a curved exhaust duct fabricated from welded sheet terminating at a large rectangular attachment face to which the jetpipe is bolted.

The free turbine is attached to the lower end of a hollow shaft, which drives a second

Fiat 4700 Company-sponsored air compressor. Single-sided centrifugal compressor, annular combustion chamber with 16 burners, single-stage compressor turbine, independent single-stage power turbine driving air-compressing centrifugal impeller at top of unit. Overall maximum diameter, 23.61in; overall height, 48.4in; dry weight, 265 lb; max rating, 530 air h.p. at 25,000 gas-generator r.p.m., with air delivery of 7.5 lb/sec at pressure ratio of 3:1; max continuous rating is 500 air h.p. with delivery of 7.36 lb/sec at pressure ratio of 2.8:1.



He S 053 Company-sponsored single-shaft turbojet. Eleven-stage compressor, can-annular combustion chamber with nine flame tubes, two-stage turbine and variable-area nozzle. Max carcase diameter, 43.5in; length as depicted, 158.5in; dry weight, 3,450 lb; max sea-level static rating, 14,300 lb dry at 6,000 r.p.m. with s.f.c. of 0.93 and mass flow and pressure ratio of 220.5 lb/sec and 7.4:1.



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centrifugal compressor similar to that employed in the gas-generator portion of the engine. The air compressor is housed in a magnesium-zirconium cast alloy scroll which terminates in an attachment face for the delivery duct beneath the rotor hub; the fresh air for this compressor is taken in vertically downwards through an intake in the centre of the upper half of the compressor casing. Accessories include a hydromechanical automatic fuel system, B.T.H. high-energy igniters and any of a variety of types of electric or low-pressure air starter. The 4700 is at present engaged in bench testing, and is scheduled to power the Fiat 7002 helicopter.

JAPAN

ISHIKAWAJIMA *Ishikawajima Heavy Industries Ltd., Tokyo.* Since 1955 negotiations have been in progress with General Electric; in June 1956 the company were authorized to manufacture spares for J47 turbojets to support U.S.A.F. and Mitsubishi-built Sabres, and it is likely that complete J47s will be produced before the end of this year.

KAWASAKI *Kawasaki Aircraft Co. Ltd., Kobe.* This aircraft company are in production with a flat-six piston engine rated at 260 h.p. Designated KAE-240, it is based on American designs, has a swept volume of 448 cu in and a weight of 440 lb.

NIPPON *Nippon Jet-Engine Co., Tokyo.* Formed by a consortium of large Japanese industrialists, this group have designed and produced a pair of small axial turbojets. Their first product, the 2,200 lb-thrust J0-1, was described and illustrated in our engine review of May 11, 1956. The engine described below is their current model.

J3-1 Many of the components of this engine are essentially similar to those of the earlier unit. It differs chiefly in having an annular combustion chamber, which, with other modifications, reduces the weight and increases the thrust. The latter is still extremely low considering the size of the engine, and it is hoped to raise it appreciably in the course of further development. Data are given in the accompanying panel. Most of the accessories are Japanese, and include high-energy ignition and either an electric or an air-impingement starter.

Three pre-production engines have been manufactured to an order placed by the National Defence Agency. One has been mounted in a pod beneath the forward fuselage of a C-46D transport of the Air Self-Defence Force for flight testing up to 200 kt at relatively low altitudes. At present it is intended that the other two powerplants will be mounted on the wing-tips of one of the Kawasaki-built T-33A jet trainers. It is envisaged that the J3-1 will eventually power the Fuji T1F-1 basic trainer.

J3-1 (not illustrated). Military turbojet. Eight-stage compressor, annular combustion chamber with 12 vaporizing burners and single-stage turbine. Max carcase diameter, 28.35in; length overall, approximately 86in; dry weight, 772 to 815 lb; max design rating, 2,645 lb dry at 13,000 r.p.m. with mass flow and pressure ratio of 51.8 lb/sec and 4.57:1, and s.f.c. of 1.08. With development the thrust should reach 3,000 lb.

POLAND

IN 1957 the entire Polish aircraft industry was reorganized, the process culminating in the formation in October of that year of a new establishment of prime importance. Designated O.K.L. (aircraft construction centre) and located at the greatly enlarged Warsaw Okecie plant, this establishment includes an engine division charged with the responsibility for designing, developing and testing all Polish aero engines. Their design team is headed by Dipl. Ing. Wictor Narkiewicz, who before 1939 supervized construction at the Warsaw Avia works and during the war was engaged on engine research at the R.A.E. Farnborough. The following are his designs which are at present under development or in production.

In addition to these powerplants, quantity production is proceeding upon the Russian AI-14R seven-cylinder radial (*q.v.*).

WN-1 This is an air-cooled flat-four with a capacity of 176 cu in, a dry weight of 128 lb and ratings of 65 h.p. for 1½ min and 58 h.p. continuously. Originally known as the PZL-65KM, its design dates from 1947. Although the initial development was successful, political considerations led to its cancellation and it was not until political tension eased in 1956-57 that the WN-1 in a slightly improved form went into production. It powers the PZL-102 Kos.

A light flat-twin which is basically half a WN-1 is now being evolved for ultra-light aircraft projects. This engine, which has yet to receive a designation, will be rated at 30-35 h.p.

WN-3 In 1952, despite an unfavourable political situation, Narkiewicz prepared a study of a new engine, the WN-3 illustrated in the diagram. The prototype was completed in 1954 and was fully developed by the end of 1955. During development the maximum power was raised from 300 to 340 h.p. without increasing the weight, and the accessories are entirely of Polish manufacture. The WN-3 is in full production, principally for the TS-8 Bies trainer; some new designs, including the four-engined MD-12, will also be equipped with the engine.

WN-4 This is a special helicopter version of the WN-3. It is fitted to the BZ-4 Zuk, with the crankshaft vertical.

WN-5 A geared version of the WN-3, the WN-5 was rated at 450 h.p. In the absence of official support it did not progress beyond the detailed study stage.

WN-6 Evolved in 1956/57, this attractive air-cooled flat-six unsupercharged engine has cylinders slightly larger than those of the WN-1 and a swept volume of 421 cu in. Features include a magnesium-alloy crankcase divided into port and starboard halves, a conventional carburettor with manually-operated altitude control, a compressed-air or electric starter and provision for a D.C. generator, air compressor and constant-speed unit. Weighing 346 lb, the WN-6 has a take-off power of 180 h.p., a continuous rating of 160 h.p. and an economical cruising power of 140 h.p. at 3,200 r.p.m. with a specific consumption of 0.48 lb/hr/b.h.p. It runs on 72 octane fuel. The WN-6 is intended for large-scale production and will be fitted to M-2 light aircraft. The WN-6R is fitted with a 0.66:1 reduction gear and has corresponding ratings of 220, 185 and 155 h.p. at considerably increased r.p.m.

WN-7 Basically a four-cylinder version of the WN-6, this engine weighs 231.5 lb and has take-off, maximum continuous and cruising ratings of 125, 110 and 95 h.p. The WN-7R incorporates a 0.63:1 reduction gear and has a take-off rating of 145 h.p.

Jet Engines The bulk of Poland's experience with sophisticated gas turbines has been obtained with the licence production of Russian turbojets of the Klimov VK-1 (Nene-derivative) type. The first engines, rated at 5,955 lb dry, began to leave the lines in 1955 and it is believed that production is continuing upon the VK-1A rated at 7,950 lb with afterburner.

Since the formation of the O.K.L., research into gas turbines has been continued and is at present concentrated upon Narkiewicz's light turbojet (intended for the TS-11 Iskra basic trainer) and a turboprop rated at 1,000 s.h.p. (which is intended to power a twin-engined version of the MD-12 light transport). No details are available on these projects, and it is likely that development is proceeding relatively slowly since everything is having to be done from scratch.

At the original I.L. (Aviation Institute), Dipl. Ing. S. Wojcicki conducted the development of several experimental pulsejet and ramjet units between 1952 and 1956. The smallest pulsejets, rated at 22 lb thrust, were test flown in a Bocian two-seat sailplane and were based upon the original designs of SNECMA; two of Narkiewicz's 24 lb-thrust ramjet units are fitted to the Trzmiel ultra-light helicopter which began experimental testing in 1957. The largest units in this class are subsonic ramjets and an example rated at 440 lb has been publicly displayed.

Finally, a series of meteorological rockets is being designed at the Academy of Mining and Metallurgy in Krakow. The work began at the end of 1957; the first design, the RM-1 liquid-fuel rocket, was successfully fired on October 10 last year and is envisaged as the last stage of a three-stage rocket designated RM-3, the RM-2 being the RM-1 plus the second stage.

SPAIN

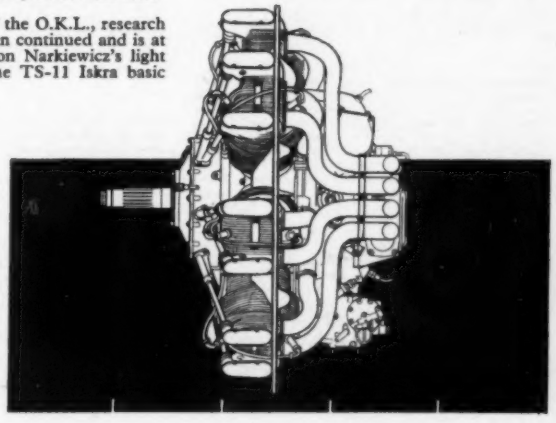
ENMASA *E.N.M.A., S.A., Antonio Maura 4, 2°, Madrid.* Now celebrating the completion of 50 years of unbroken operations, the national Spanish aero-engine organization is justly proud of a large new factory in San Andrés de Barcelona. The following are the company's current range of powerplants; no mention has yet been made of any gas turbine work.

Beta B-4 The latest version of this well-known single-row radial remains in limited production. It is normally equipped with a hydraulic Rotol propeller. Each of the nine cylinders has a bore and stroke of 155.5 and 174.6mm, giving a displacement of 29.85 litres. Compression ratio is 6.4:1, permitting the use of 87-octane fuel and giving a maximum rating of 765 h.p. at 2,200 r.p.m. Dry weight is 1,069 lb.

Sirio S-2 This is the latest version of an attractive single-row radial, and differs from earlier versions in having a reduction gear. It normally drives a two-blade, constant-speed, Rotol propeller. The Sirio has a single row of seven cylinders, the bore and stroke of 150 and 145mm giving a displacement of 17.93 litres. Supercharged and geared, the

ENMASA Alcion (not illustrated). Commercial radial piston engine. Single row of seven cylinders, with supercharger and reduction gear. Bore and stroke, both 4.33in; swept volume, 447 cu in; dry weight, 496 lb; max rating, 271 h.p. at 3,000 r.p.m.; cruising rating at 6,500ft, 172 h.p. at 2,400 r.p.m.

ENMASA Flecha (not illustrated). Commercial flat-four piston engine. Bore, 4.14in; stroke, 3.94in; swept volume, 211 cu in; dry weight, 220 lb; max rating, 91.7 h.p. at 2,600 r.p.m.



WN-3 Piston engine. Seven-cylinder air-cooled radial, unsupercharged and with direct drive. Diameter, 43.5in; length, 34.9in; bore, 5.31in; stroke, 5.27in; swept volume, 818 cu in; dry weight, 530 lb; max (5-min) rating, 340 h.p. at 2,500 r.p.m.; cruising rating, 237 h.p. at 2,100 r.p.m. with s.f.c. of 0.48 lb/hr/h.p.

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maximum rating (5 min) is 493 h.p. at 2,300 r.p.m.; dry weight is 785 lb.

Alcion Still in the development stage, a small number of prototypes have been subjected to extensive bench testing and one of these will shortly be submitted to the Instituto Nacional de Técnica Aeronáutica, Esteban Terradas, for official type-testing.

Tigre G-IV-B.5 Made in great numbers in several versions, the Tigre remains in reduced production in its latest B.5 form. An inverted, air-cooled, four-in-line unit, it is ungeared and unsupercharged and has a maximum rating of 148 h.p. at 2,300 r.p.m.

Flecha The first Spanish flat-four, the Flecha was awarded a "Oficialmente Homologado" by the I.N.T.A. last year. Only a small batch has been constructed up to the present time.

SWEDEN

FLYGMOTOR *Svenska Flygmotor A.B., Trollhätten.* Since 1950 this company has concentrated its activities chiefly upon two turbojets, both originally of British design. These engines, which are described below, have both been extensively developed in Sweden, and Flygmotor are virtually self-supporting in being able to evolve improved types of engine and to design and develop complete control systems, accessories, afterburners and other equipment, completely unaided. An indication of their ability is afforded by the fact that more than 1,000 RM2s and several hundred RM5s have been delivered, and their failure rate in arduous military service has been very low. Flygmotor are also developing an aircraft rocket motor, described below, and are working on subsonic and supersonic ramjets.

RM2 This is the Swedish designation of the Flygmotor-built de Havilland Ghost. Basing their work on the British Ghost 50, the Swedish engine is the only fighter Ghost to have a central (i.e., not bifurcated) intake. Production began in 1950, and some thousand had been delivered when contracts were completed three years ago. All are fitted to the three versions of the Saab-29 fighter, attack and reconnaissance aircraft, and virtually all RM2s have been brought up to RM2B standard by fitting a short afterburner of Flygmotor design. This was the first Swedish afterburner, and it established a national pattern in employing fully variable reheat augmentation, flameholders integrated with the burners and a reheat fuel pump driven by a bleed-air turbine. The RM2B weighs 2,510 lb and has maximum ratings of 4,750 lb dry and 6,200 lb with maximum reheat.

RM5 Under this designation Flygmotor have manufactured a large number of Rolls-Royce Avon 100-series turbojets, under licence from the British company. The standard version is the RM5A, data for which are given in a panel; the basic engine corresponds closely to the British RA.7/RA.21 family, and the Swedish derivative, equipped with a variable-augmentation afterburner, is the powerplant of the Saab-32A Lansen two-seat attack aircraft. The RM5A is no longer in production.

RM6 Full production is now in progress upon a Swedish version of the Avon 200 with afterburner. The first Flygmotor model to reach the production stage was the RM6B, illustrated, which powers the Saab-32B Lansen all-weather fighter. The basic turbojet is a 10,000 lb thrust engine essentially similar to the British RA.28, and it has been matched with a Flygmotor-designed afterburner of high efficiency. Features of the latter include a sharply diverging diffuser, a clearly defined maximum-area section at which is located the assembly of circular vee-gutter flameholders and fuel burners, and a fully variable nozzle with left- and right-hand eyelids.

Production has also commenced upon a more advanced engine for the Saab-35A Draken all-weather intercepter. The basic turbojet in this case is a Swedish counterpart of the latest British fighter Avons of RA.24 standard, undoubtedly with air-cooled turbine blades and a steel compressor casing to withstand the internal pressures generated during supersonic flight at low altitudes. The ratings of the Draken engine have not been divulged, but may be assumed to be approximately 11,250 lb dry and 15,000 lb with full reheat from the Flygmotor afterburner. The latter assembly is of a later design than that fitted to the RM6B, and has a larger final nozzle.

VR3 Under this designation Flygmotor have been engaged in the development of a small liquid-propellant rocket motor, tailored to the boost propulsion of aircraft. The propellants are H.T.P. and kerosine, and they are fed by turbopump to a single throatless chamber. Thrust is variable between 40 per cent and 100 per cent under the control of a single lever which also governs the automatic starting and shut-down circuits. Overall length is approximately 3ft 3in; dry weight is 165 lb, exclusive of the turbopump group, and the thrust at 65,000ft is 5,700 lb.

SWITZERLAND

SINCE 1951 Sulzer Brothers at Winterthur have manufactured at least 250 Ghost turbojets under licence from de Havilland Engines. A licence may be obtained in respect of a more advanced unit, such as the Sapphire 7 or J79.

U.S.A.

AEROJET *Aerojet-General Corporation (Subsidiary of the General Tire & Rubber Company), Azusa, Cal.* Aerojet-General claim to be the largest American rocket company and they are certainly the world's biggest producer of missile boosters and a.t.o. rockets.

The company's largest propulsion contract is that for the XSM-68 Titan intercontinental ballistic missile for the U.S. Air Force. The first stage of this huge weapon is powered by an XLR87-AJ-1 package which incorporates a pair of gimbal-mounted chambers, each rated at 150,000 lb at sea level and running on liquid oxygen and RP-1. The second stage has a single-chamber XLR91-AJ-1 rated at 60,000 lb at sea level on the same propellants. Aerojet are also likely to handle the bulk of the advanced development and production of the solid-propellant propulsion system (the first stage of which incorporates four nozzles with jet deflectors) for the U.S. Navy Polaris ballistic missile.

AIRCOOLED MOTORS *Aircooled Motors Inc., Liverpool Road, Syracuse 8, N.Y.* Having lost most of the fixed-wing business to Continental and Lycoming, Aircooled—manufacturers of the Franklin engines—are concentrating on helicopter propulsion. The 6V4 flat-four and 6V6 flat-six vertical-crankshaft engines are made in great quantity for Bells, Hillers and other applications. These were described in our earlier engine issues, and the most recent development is the turbo-supercharged flat-six engine. Designated 6VS, and briefly described in our July 26, 1957, issue, this engine can hold its power of 225 h.p. up to 10,000ft.

ALLISON *Allison Division of General Motors Corporation, Indianapolis 6, Indiana.* Since our last engine review was written, Allison have concentrated their aero-engine work on a rather narrower front than previously and are today devoting the major part of their effort to turboshaft engines. Nevertheless, more than 90 per cent of the company's engines at present in service are turbojets, the most important types being J33, J35 and J71. Full details of these have been given in previous engine review issues (the last being on July 26, 1957) and there is very little that can be added, in view of the almost complete cessation of development of these three well-proven and well-known units.

The only turbojet on which Allison have been busily engaged in recent years is a large single-shaft engine, rated at some 25,000 lb dry, intended for flight Mach numbers in excess of 2.5. A great deal of rig running has been completed and extensive experiments have taken place using a variety of high-energy fuels, but it now seems certain that the engine will not succeed in the face of the G.E. J93 and the P. & W. J58. The military type number for this engine was J89.

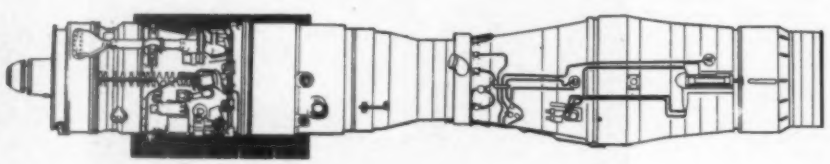
After an unhappy and abysmally uninspiring decade trying to evolve a good turboprop, Allison finally found the right formula with the T56. This engine, which was really a direct outgrowth of the earlier T38 but properly engineered, is now in wide service with the U.S.A.F. and R.A.A.F. and is performing admirably. Its success has been instrumental in enabling the company to achieve commercial rewards with the closely related Model 501 turboprop, now entering large-scale airline service as the powerplant of the Lockheed Electra. Its successor is the entirely new Model 550, which now has a U.S.A.F. development contract as the T61. Allison's new hope for the future lies in the outstanding Model 250 turboshaft engine, which is likely to be the first gas turbine in the 250 h.p. class to offer an effective combination of low specific consumption and modest capital cost.

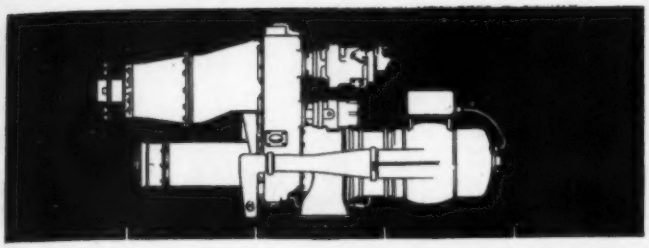
Model 250/T63 As the aero division of the world's largest privately owned automotive company, Allison are, from several viewpoints, in a singularly fortunate position. Their sheer size is, with the Model 250, enabling them to tackle a task in which success has eluded all who have previously attempted it: to develop a gas turbine rated at around 250 h.p. which can hold its own in first cost and operating economy with established reciprocating engines. Allison are likely to succeed as a result of their engineering experience, extensive research facilities and ability to cost production engines over a tremendous total manufacturing run.

It is to the U.S. Army that Allison owe the chance to go ahead with this engine. In the winter of 1957-8 that Service held a hard-fought competition for a 250 s.h.p. engine suitable for the propulsion of a wide range of vehicles, including fixed-wing aircraft, helicopters, flying platforms, surface and amphibious craft and even small ships. Allison's

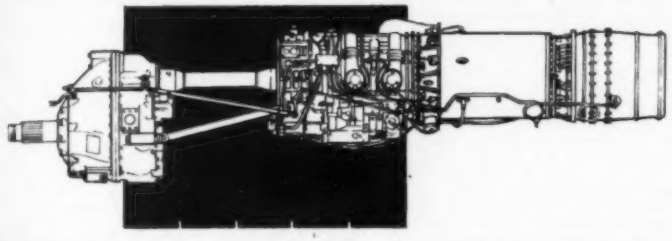
Flygmotor Avon RM5A (not illustrated). Military turbojet with afterburner, based on the Rolls-Royce Avon 100 series. Twelve-stage compressor, eight combustion chambers, two-stage turbine and S.F.A.-designed afterburner with two-position nozzle. Max diameter, across combustion chambers, 42.2in; overall length, cold, 251.96in; dry weight, 2,960.8 lb; max sea-level static ratings, 9,480 lb with reheat or 7,500 lb dry at 7,950 r.p.m. with s.f.c. of 1.9 and 0.92, respectively, the mass flow and pressure ratio being 119 lb/sec and 6.5:1.

Flygmotor Avon RM6B (below). Military single-shaft turbojet with afterburner. Fifteen-stage compressor, can-annular combustion chamber with eight flame tubes, two-stage turbine and high-augmentation afterburner with fully variable nozzle. Max diameter of engine, 41.5in; max diameter over afterburner, about 45in; overall length as depicted, about 270in; dry weight, probably about 3,400 lb; max rating, probably about 10,000 lb dry and 14,000 lb with full reheat.





Allison 250-B2 (T63-A-1) Military turboprop. Compressor with seven axial stages followed by one centrifugal stage, twin delivery manifolds to single tubular combustion chamber, single-stage compressor turbine and two-stage independent power turbine. Overall width, 15.8in; height, 19.3in; length as depicted, 38.9in; dry weight, probably bare, 106 lb; guaranteed performance, max rating (up to 100 deg F), sea-level, static, 250 s.h.p. at 2,000 propeller r.p.m. with s.f.c. of 0.70 at 59 deg F rising to 0.73 at 100 deg F; 75 per cent power, 159 s.h.p. with s.f.c. of 0.81; military rating at 6,000ft, static, 59 deg F, 206 s.h.p. with s.f.c. of 0.72.



Allison 501-D13 Commercial single-shaft turboprop. Fourteen-stage compressor, can-annular combustion chamber with six flame tubes and four-stage turbine. Overall width, 27in; max overall height, 36in; length as depicted, 145.2in; dry weight, bare, 1,750 lb; max rating, 3,460 s.h.p. (3,740 e.h.p.) at 13,820 r.p.m. with mass flow of 39 lb/sec, pressure ratio of 9:1 and s.f.c. of 0.54; max cont. cruise rating at 25,000ft at 360 kt, 1,850 s.h.p. (1,905 e.h.p.) also at 13,820 r.p.m. with s.f.c. of 0.46.

entry, the Model 250, was not only technically outstanding, but was also the only one whose sponsor was willing to bear all development costs in excess of a relatively small sum (reported to be $4m). A joint U.S. Army/U.S.A.F. development contract was announced last June 25. The military designation is T63.

In all small gas turbines, manufacturing costs have virtually precluded the adoption of an axial compressor. Allison have evolved a method by which complete axial stages, blades and all, can be precision cast in an aluminium-cobalt alloy, the resulting assembly needing virtually no machining and costing roughly one-quarter as much as by the next most economic method. Even the centrifugal stage, which leads to the final discharge volute, is a precision casting which is practically a finished part when it leaves the mould.

Any normal hydrocarbon fuel may be employed with the 250, and it is injected from a Duplex nozzle mounted centrally in the large reverse-flow combustion chamber which projects from the end of the engine opposite to the intake. The gases pass through the compressor turbine and free power turbine, and are then turned downwards through 90 deg to exhaust from the underside of the powerplant. The main output pinion is mounted at the front of a hollow shaft which surrounds the central shaft joining the compressor to its turbine. From the output pinion a train of gears leads upwards to a row of accessory drives and to any of a variety of power take-offs which can be adapted to suit the requirements of the vehicle in which the engine is fitted. The variant illustrated is the turboprop version, in which a reduction gear reduces the speed of the output shaft to a maximum of 2,000 r.p.m.

One of the good features of the 250 is that its designers have deliberately limited the maximum shaft horsepower to 250. The engine as it stands is potentially capable of higher powers, but this artificial restriction enables the engine to deliver its full rated power up to 100 deg F ambient, or on standard days up to altitudes of from 7,000 to 13,000ft, depending on forward speed. The restriction is applied by an automatic hydromechanical control system, operating on the gas-generator section of the engine and controlled by torque-meter pressure sensers and by four thermo-couples which limit turbine-inlet temperature to 1,228 deg K. Great efforts have been made to render the engine well suited to maintenance by unskilled personnel in difficult conditions; the complete compressor can be removed by undoing three bolts and disconnecting an oil pipe; both the compressor and power turbines may be replaced without rebalancing, and the combustion chamber can be removed merely by disconnecting the lines to the igniter and burner and then undoing a vee-clamp. Prototype 250s are probably now running on the bench; production engines should be available within 18 months at a price which may be not more than $10,000 (£3,571).

Reference: Sept. 19, 1958 (description and cutaway drawing).

Model 501 Last December this unusual, but efficient and reliable, single-shaft engine became the first non-British turboprop to enter airline service. From the outset it has been tailored to the Lockheed Electra airliner, and it utilizes major portions very similar to those employed in the military T56 described later. The chief difference lies in the fact that in the military engine the reduction gear is mounted above the drive-shaft, so that the engine intake is situated beneath the propeller spinner.

The standard commercial engine is the 501-D13, which is described and illustrated here. In all Electras except those for K.L.M. the engine is matched with an Aeroproducts four-blade propeller, incorporating β control. By biassing the engine governor and opening compressor bleed ports, special provision has been made for reducing propeller r.p.m. to 970 to reduce noise on the ground. In the air the 501 is a constant-speed engine, operating at 13,820 r.p.m.

Last September the D13 was cleared by the C.A.A. (now the F.A.A.) to an initial airline overhaul life of 1,000 hr. This figure, achieved three months before scheduled services began, is particularly commendable, and arises largely as a result of the extensive experience gained with the military T56. In our last engine issue we briefly described the advanced 501-D15, with transonic flow through the first three compressor stages and shrouded first and second turbine stages. No further news is available upon the progress of this engine.

Model 550 Since our last engine review issue the 550, originally a private venture, has become a military project as the T61. Sponsored by the U.S. Air Force, it is a two-spool engine, with a pressure ratio of at least 13 : 1 and a design rating in excess of 5,000 e.h.p. It therefore must be regarded as a slightly smaller competitor of the Rolls-Royce Tyne, and is initially foreseen as the powerplant of the winner of the U.S.A.F. competition for an advanced all-weather, high-altitude radar picket aircraft. Bench tests have been in progress for a considerable period, but the engine is not yet thought to have flown and is heavily classified by military security.

T56 Standard powerplant of the Lockheed C-130 military freighter, the single-shaft T56 has now logged more than 660,000 hr, the vast proportion of this being in military service with Tactical Air Command. The 50 hr flight clearance test of the YT56 was completed in September 1953; flight testing began with an engine mounted in a B-17 in March 1954 and intensive trials with engines fitted to a pair of YC-131C aircraft took place during the summer of that year. Production deliveries for the C-130 began in January 1955 and some 1,500 engines have now been delivered. Nearly all the engines currently in service are of the T56-A-1A model, rated like the Electra engine at 3,460 s.h.p. (3,750 e.h.p.) and matched to a three-blade 15ft propeller. The version currently in production is the T56-A-7, rated at 3,755 s.h.p. (4,050 e.h.p.) and used in the Lockheed C-130B with a four-blade propeller. Features include a Bendix fuel/air combustion starter and water injection for restoring power in tropical conditions. Still under development is the T56-A-10W, with a rating of 4,585 e.h.p. with water/alcohol injection.

BELL *Rocket Engine Department, Bell Aircraft Corp., Buffalo 5, N.Y.* In our 1957 engine review issue a general appraisal of the work of the rocket engine department was given. Production of acid/aniline rocket motors for Nike Ajax missiles has now ceased, and the triple-barrel liquid-oxygen/kerosine engine for the company's own GAM-63 Rascal air-to-surface missile is also practically out of production. The only new project is the Hustler rocket engine used in the second stages of orbital and space vehicles boosted by a Thor or Atlas. The Hustler has a single chamber pump-fed with fuming nitric acid and JP-4 fuel, and was originally developed for the propulsion of a pod carried by the B-58 Hustler.

BOEING *Boeing Airplane Company, Seattle 24, Washington.* For 15 years this immense company has been active in the field of small gas turbines, and the 502 series of engines has established a high reputation for reliability and trouble-free service in marine, industrial, vehicular and aircraft applications. Bench-testing of the first engine began in 1947, the output being 100 h.p. and the specific consumption 1.8; the current production engine is the 502-10C, rated at 240 s.h.p. with a specific consumption of unity. Some 700 similar engines have been delivered. Aircraft applications include shaft-drive and tip-drive helicopters and the RP-77D target drone developed for the U.S. Army by Radioplane. The latter is powered by the 502-10F turboprop, rated at 300 h.p. at 3,400 r.p.m. with a specific consumption of 0.95 and a dry weight of 300 lb. These drones can exceed 400 m.p.h. and one recently reached 46,500ft. Late last year a Cessna L-19 powered by a 502-10F flew non-stop from Seattle to Ft. Rucker, Alabama, cruising at 20,000 to 27,000ft.

T60 Boeing's industrial products division have for about a year been busily engaged in the development of an entirely new powerplant. Known as the Boeing Model 520-2, the engine is under development for the Navy Bureau of Aeronautics and carries the Service designation of T60. The manufacturer's own description states that the engine "features aerodynamic refinement of single-stage compression and expansion. . . . Other features to simplify installation, operation and maintenance include eductors for ventilation cooling, automatic starting and control, accessibility for inspection and replacement, and field-interchange of rotor components without dynamic and static balance of the assembly. Main rotor bearings are floating sleeve and slipper types." The illustration and specification are appropriate to the -2 unit, which has been on test since March 1958 and reached the specification ratings of 400 s.h.p. and 0.72 specific consumption at the beginning of

AERO ENGINES 1959 . . .

this year. The company state that the advance of the T60 has been so rapid that 500 s.h.p. and 0.65 specific consumption is forecast for an early date, and a vigorous weight-reduction programme should ensure a specific weight of about 0.45 lb/s.h.p. for the advanced engine. The original Navy contract was particularly concerned with helicopters, but applications for the T60 include fixed-wing aircraft and drones.

CONTINENTAL *Aircraft Engine Division, The Continental Motors Corporation, Muskegon, Mich.* Since 1951 Continental have been engaged in the development and production of a range of Americanized versions of several small gas turbines designed by the French Soc. Turboméca. The most important of these is the J69 (derived from the Marboré) described below. Other variants are the Model 220 (military XT51) turboshaft engine (Artouste), the Models 320 and 324 turbojets (respectively Palas and Arbizon) and the Model 160 air compressor (Autan). In addition, the Model 141 (Palouste) air compressor has been made in large numbers for installation in pressure-jet helicopters and U.S.A.F. ground vehicles, and an airline variant for starting jet transports is being marketed. The following are notes on the company's most important current engines.

Gas Turbines

J69 Well over a thousand of these engines have now been delivered, for installation in basic trainers and target drones. The most common long-life variant is the Model 352, J69-T-9, which is fitted to the Cessna T-37A of the U.S.A.F. The very similar T-2 is fitted to corresponding Navy aircraft. Compared with the French Marboré II, the Continental engine has slightly greater thrust and completely different accessories. The illustration depicts the T-9 variant. The T-19B is the standard drone powerplant, rated at 1,060 lb and fitted to the Ryan Q-2A Firebee; a slightly hotter missile engine is the T-27 rated at 1,150 lb. Continental have gone ahead on their own in evolving an improved series of J69s with an axial stage ahead of the centrifugal compressor, thus bringing the design point close to that of the latest Turboméca engines. The most highly rated of the new versions is the T-29, which will be fitted to the supersonic Ryan Q-2C drone at a rating of 1,700 lb thrust. The T-29 weighs 335 lb, some 23 lb more than the earlier drone engines.

J87 Continental's experience with the Turboméca engines has prompted them to develop a gas turbine more or less from scratch. The J87 is a small turbojet sponsored by the U.S. Air Force, and in view of the latter fact all details are restricted. It is likely, however, to be the smallest American turbojet, with a rating of less than 1,000 lb thrust.

Piston Engines

During the past year the company have introduced a geared version of the popular O-300 flat-six. The GO-300 series are accordingly cleared to run at 3,200 r.p.m. to give 175 h.p.; a conventional carburettor is retained. A completely new version of the well-known O-526 flat-six is the FSO-526-A helicopter engine; less powerful than the fixed-wing version, it is rated at 270 h.p. for both take-off and continuous purposes, and is cooled by a shrouded gear-driven fan turning about a vertical axis at the front of the horizontal crankshaft.

FAIRCHILD *Fairchild Engine Division, Deer Park, Long Island, N.Y.* In 1947 Fairchild initiated the design of the J44, a small single-shaft turbojet of unique design. This has ever since been the Engine Division's "bread and butter" line, and it has achieved some success in the propulsion of target drones and special missiles. In 1955 work began on a more advanced engine which became the J83; rated in the 2,000 lb class, it continued the fabricated-sheet monocoque type of construction pioneered with the J44. Fairchild hoped to obtained military and commercial sales for the J83 but in the event its whole development was tied up with the SM-73 Goose diversionary missile, for which it provided cruise propulsion. This vehicle was cancelled late last year. As a result the J83 was also cancelled, 2,000 of the Engine Division's 2,600 employees had to be laid off, and work is restricted to J44 development and a search for new business.

J44 All engines of this family are single-shaft units with the configuration given in the data panel. The first short-life version for unmanned applications was run on the bench in 1948, service-tested in 1949 and flown in a missile in 1950. The J44-R-20B variant is the standard powerplant of several versions of the Ryan Firebee target drone, and a number of engines have completed more than one flight after being recovered from the sea or desert. The J44-R-26 is an uprated version, with a rating of 1,100 lb, on which development is continuing. The R-24 was built in some numbers as the powerplant of the AUM-1 Petrel air-to-underwater missile. The R-3 is used in wing-tip nacelles on C-123B Provider assault transports of the U.S.A.F. to provide boost thrust, and the FT-101E is a commercial version for similar applications.

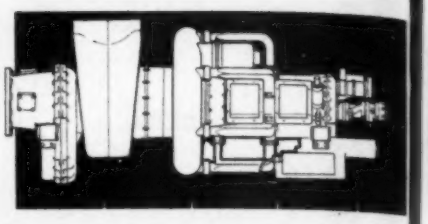
GENERAL ELECTRIC *The General Electric Company, Aircraft Gas Turbine Division, Cincinnati 15, Ohio.* Since their introduction to the gas turbine field in 1941 (when they started the development and production of engines based on Sir Frank Whittle's designs), G.E. have manufactured more aircraft turbojets than any other company. The production of the J47 alone totalled no fewer than 33,000 engines when the last was delivered in 1955. These units were fully described in our engine issues of April 9, 1954, and May 11, 1956; many are at present employed as hack units in research programmes, particularly those concerned with nuclear propulsion.

Following the J47 came the J73, a more modern single-shaft turbojet, and the present culmination of this work is the excellent J79, the first of a family of variable-stator engines which permit the achievement of high pressure ratios without having recourse to a two-spool configuration. The J79 and its commercial counterpart, the CJ-805, are being intensively developed, both as straight jets and as the basic units from which aft-fan engines are being evolved. The most important engine for the future is the J93, which is again a completely new design.

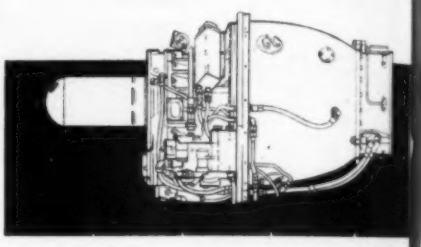
G.E.'s Small Aircraft Engine Department at Lynn, Mass., has for some years been engaged in the development of the T58 turboshaft engine, and also holds contracts for the J85 turbojet and the T64 2,500 h.p. engine.

In the nuclear field General Electric have a head-start over all other firms in the United States, in that their research contract has operated at full pressure for many years past and is accordingly closer to providing flyable hardware than that of any other company. From the outset G.E. have been investigating closed-cycle systems, and at Idaho Falls the company's Aircraft Nuclear Propulsion Department have succeeded in running J47 hack engines entirely on the heat released from a nuclear reactor.

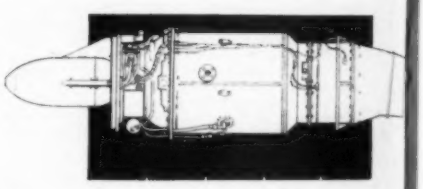
At present the engines are started on conventional hydrocarbon fuel; the reactor employed is a water-moderated assembly cooled by air which is gradually admitted to the combustion chamber of the running turbojet. The latter is built up from portions of J47s in the following manner: atmospheric air is induced at the intake, compressed conventionally and discharged through a large duct which leads directly to the reactor. The air is then passed through the reactor and out again, and thence through a large combustion chamber for hydrocarbon fuel from which hot gas



Boeing Model 529-2 (YT60-BO-2) Military turboshaft engine. Centrifugal compressor, twin reverse-flow combustion chambers, inwards-radial compressor turbine and independent single-stage axial power turbine. Overall width, 25in; overall height, 26in; overall length, 57.25in; dry weight, 335 lb magnesium or 360 lb aluminium; max rating, 400 s.h.p. at 6,000 r.p.m. with mass flow of 5.5 lb/sec, pressure ratio of 4.4:1 and s.f.c. of 0.72 lb/hr/b.h.p.; normal continuous rating, 350 h.p.

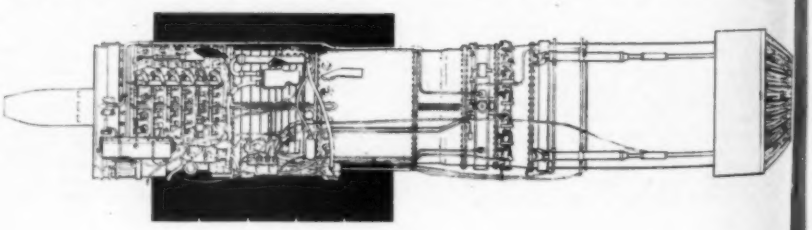


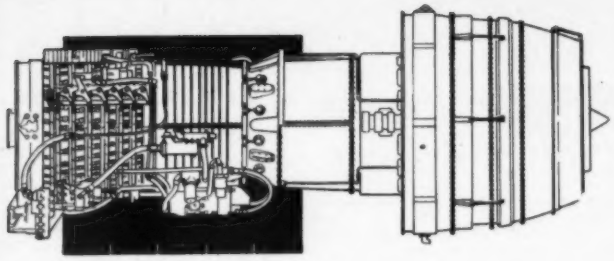
Continental Model 352 (J69-T-9) Military turbojet. Centrifugal compressor, annular combustion chamber with rotating fuel-injection unit and single-stage turbine. Overall diameter, 22.3in; overall length, 50in; dry weight, 364 lb; max rating, 920 lb dry at 22,700 r.p.m. with s.f.c. of 1.13. The later J69-T-25 is the same size and weight and is rated at 1,025 lb with s.f.c. of 1.14. The first short-life engines, of T-19B type, weigh 312 lb and give 1,060 lb with s.f.c. of 1.27.



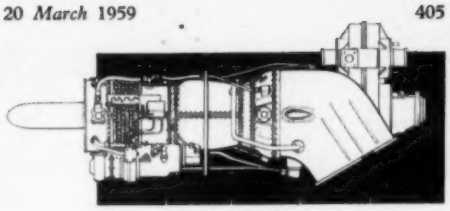
Fairchild J44-R-26 Company-sponsored single-shaft turbojet. Single-sided compressor, initially axial but terminating as a centrifugal, annular combustion chamber with 12 burners and single-stage turbine. Overall diameter, 22.3in; length as depicted, 92in; dry weight, 365 lb; max rating, 1,100 lb dry at 15,780 r.p.m. with mass flow of 25 lb/sec, pressure ratio of 3.25:1 and s.f.c. of 1.30.

General Electric J79-GE-3A Military single-shaft turbojet. Seventeen-stage compressor with variable-incidence inlet guide vanes and first six stators, can-annular combustion chamber with ten flame tubes, three-stage turbine and afterburner with fully variable con-di nozzle. Overall diameter, 32.5in (36in at nozzle shroud); length as depicted, 204in; dry weight, approximately 3,190 lb; max rating, 11,000 lb dry or approximately 16,000 lb with full reheat with mass flow of 162 lb/sec, pressure ratio of 12:1 and s.f.c. (dry) of about 0.8.

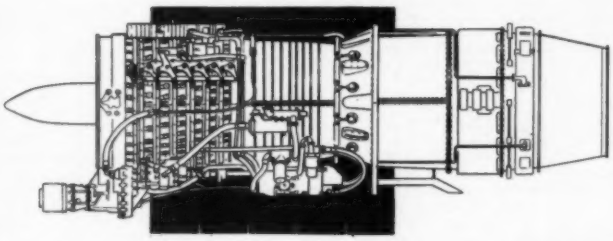




General Electric CJ-805-21 Commercial aft-fan engine. Basic gas-generator turbojet similar to CJ-805-3, with additional free-floating assembly of double-deck blades, comprising inner turbine blades and outer fan blades working on free air in an overall duct. The overall diameter of the fan duct is approximately 55in and the length from fan intake to tailpipe connection is 42.9in; the distance from fan intake to turbojet intake is 101.1in; unequipped dry weight, approximately 3,750 lb; max rating, in the 15,000 lb class; the mass flows are about 165 lb/sec (turbojet) and 257 lb/sec (fan) and the s.f.c. is below 0.7.



General Electric T58 Military free-turbine engine for helicopters. Ten-stage compressor with variable incidence on the inlet guide vanes and succeeding three stator rows, annular combustion chamber with 16 injectors, two-stage compressor turbine, single-stage power turbine and reduction gear at rear end. Basic diameter at the max flange, 16in; intake diameter, 11.4in; height as depicted, 27.3in; basic power-section length, 59in; length as depicted, 71in; dry weight, 250 lb or 325 lb with reduction gear; ma rating, 1,024 s.h.p. (1,050 without reduction gear) at 19,500 power-turbine r.p.m. with mass flow of 12.4 lb/sec and pressure ratio of 8.3:1; max continuous cruise rating, 875 s.h.p. with s.f.c. of 0.69; the T58-GE-8 is uprated to 1,250 s.h.p.



General Electric CJ-805-3 Commercial single-shaft turbojet. Seventeen-stage compressor with variable incidence inlet guide vanes and first six stators, can-annular combustion chamber with ten flame tubes and three-stage turbine. Front-frame diameter, 31.6in; max overall diameter, 36.6in; length of carcase, excluding bullet end tailcone, 110.3in; dry weight without equipment, 2,780 lb; max rating, 11,000 lb dry with pressure ratio of 12:1 and s.f.c. of under 0.8.

can be delivered to the J47 turbine. As the reactor is brought on the line so can the flow of hydrocarbon fuel be restricted until the engine becomes self-sustaining on reactor heat alone. Much more advanced testing is currently taking place. In particular, operating temperatures are approaching the level at which an airborne unit begins to make sense, and it has been suggested that after perhaps two more years of research it will be possible to design an optimum aircraft to meet the U.S. Air Force WS-125 nuclear powered bomber specification. (It has, of course, been theoretically possible to build a nuclear-powered aircraft for some years past, but it would have been far from worthwhile.)

J79 As the powerplant of the Convair B-58 and of production versions of the Lockheed F-104, the J79 has now logged a total of well over 100,000 flight hours, and its severe early teething problems seem to be largely over. Advanced versions of the engine have now been selected for later versions of the F-104, and for the North American A3J-1, and the McDonnell XF4H-1, and the J79 is also fitted to the Grumman F11F-1F Super Tiger and the Chance Vought Regulus II missile. It is significant that all these aircraft are capable of speeds greater than Mach 2, and all their engines have afterburners.

The basic layout of the engine is evident from the drawing and data panel, and a full description was published on page 133 of our July 26, 1957, issue.

J93 With this engine G.E. hope to establish a position in the propulsion of future American military aircraft which will be commanding as that held by the J47 in the heyday of the B-47 and F-86. Owing to its immense importance as the first choice of powerplant for the North American B-70 Valkyrie intercontinental bomber and the North American F-108 long-range all-weather intercepter, the J93 is heavily guarded by military security. It is, however, known that it will be a high-airflow, single-spool engine, probably with a design pressure ratio not greater than 7 : 1 operated in conjunction with a large afterburner and convergent/divergent variable-area nozzle which will increase the maximum rated thrust from 20,000 to around 30,000 lb. The design Mach number is between 3 and 3.25, and from the outset the engine will be designed to burn high-energy fuel in the afterburner (and at a later date in the main combustion chambers as well). Rig running of components began more than a year ago, and it is almost certain that complete engines are at present undergoing bench testing at Evendale (Cincinnati).

CJ-805 G.E. have long wished to enter the commercial market with their gas turbines, and the advanced design of the J79 military turbojet prompted them to take the bold step of developing an airline variant as a company venture. Designated CJ-805, this engine incorporates major components of the J79, although the detail engineering has been biassed in favour of long life and low-cost maintenance. The upper and lower halves of the front and rear compressor casings, combustion-chamber casings and turbine casings (respectively weighing 140, 90, 30 and 65 lb each) can be removed individually to provide access to all blading and to the ten flame tubes, and the hydro-mechanical control system and all engine accessories can be removed and replaced without touching any other part of the engine.

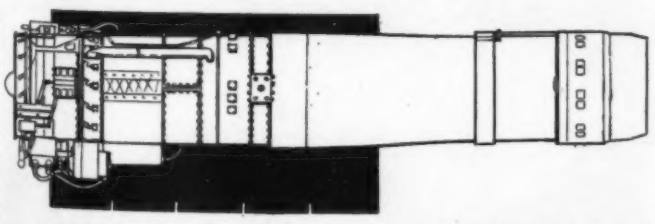
Flight development of a prototype CJ-805 was conducted at Edwards A.F.B. with a Douglas XF4D Skyray leased from the U.S. Navy. Last September, when 150 hr had been flown, the prototype was replaced by a production CJ-805-3. Ten hours were flown on the first day (September 8) and several hundred hours have since been logged by this aircraft simulating airline schedules. The flight test schedule required a total of 420 flight hours by the end of last year, and the current figure is probably in excess of 600, excluding the 150 logged on the prototype. The XF4D is also engaged in engineering tests, including air starting above normal altitudes and investigation of behaviour at excessive Mach numbers and ram pressures, acceleration and deceleration and response during mishandling.

In the same month (actually on September 9) the CJ-805-3 was awarded a C.A.A. (now F.A.A.) type certificate. Included in the testing were a simulated 120 per cent overspeed, tests with jetpipe temperature 75 deg F over the maximum and ingestion of 1.25in hailstones up to maximum aircraft flight speed. In October a pair of 805-3s was installed in a Douglas B-66 leased from the U.S. Air Force, and this aircraft has since been engaged in intensive test programmes operating from Edwards. Each pod is a facsimile of the powerplant of the Convair 880 transport and the test-bed is also equipped with CV-880 generators, constant-speed drives and electrical controls. Earlier this month this aircraft flew 2,295 miles non-stop from California to Washington D.C. in a time of 3 hr 36 min, and it is likely to perform similar missions throughout this year while logging several thousand hours of simulated airline schedules.

The first set of production -3 engines left G.E.'s plant at Evendale last September. Rohr Aircraft have built these into complete pods with noise-suppression nozzles and thrust reversers, and four such pods were fitted to the first Convair 880 which started its flight-test programme in January. Performance of the engine in this aircraft has since been most satisfactory.

At the start of the CJ-805 programme it was announced that the following would be the first major variants: -2, de-rated to about 9,000 lb; -3 (illustrated); -11, growth version rated at about 12,000 lb; -13, augmented version of the -11. These projects have been largely superseded by the -21 fan engine.

CJ-805-21 In an attempt to produce an improved commercial powerplant, General Electric have adopted a configuration which, although in many ways attractive and frequently employed in the earliest gas turbine aero engines, has not been seen for many years. Behind the basic gas-generator a free-floating turbine has been added, with two-storey "bluckets" each consisting of an inboard turbine bucket driven by the hot primary exhaust and an outboard fan blade working in fresh air. The latter is induced at an annular intake surrounding the remainder of the engine and is constrained to follow a duct and exhaust



General Electric J85-GE-1 Military turbojet with afterburner. Axial compressor with several variable-incidence stator stages, annular combustion chamber with 18 burners, turbine probably with two stages, afterburner with variable-area, multi-petal nozzle. Overall carcase diameter, approximately 19in; overall length as depicted, 114in; dry weight, of the order of 500 lb; max rating, approximately 2,600 lb with reheat with s.f.c. of about 1.9 or 1,900 lb dry with s.f.c. of approximately 1.0.

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through an annular nozzle concentric with the central jet. The aft fan assembly is supported fore and aft by its own bearings and it rotates counter-clockwise, opposite to the rotation of the basic engine shaft, to reduce gyroscopic loads.

Such an arrangement is mechanically difficult to accomplish and aerodynamically it is no easy task to match the added turbine blades (which necessarily operate in gas already expanded and cooled through the three-stage turbine upstream) with the requirements of blade angle and tip speed for best fan performance. The by-pass ratio is no less than 1.56 : 1, yet the company succeeded in achieving the desired pressure ratio with a single stage of blading, and extensive bench testing has proved that the aft-fan assembly will meet the specified performance.

The first aft-fan engine was produced by converting a CJ-805-3 in 1957. Conversion is achieved by merely replacing the aft frame, incorporating the primary engine mounts and No. 3 bearing, by the complete fan assembly, leaving the basic gas-generator portion of the engine unchanged. Last July Convair announced the sale to American Airlines of 25 CV-600 transports, these being developments of the CV-880 powered by the -21 engine. Flight testing of the -21 is scheduled to begin in about six weeks, and fully certificated powerplants are due to be produced and shipped in 1960. The first CV-600 is scheduled for introduction to American Airlines service in 1961.

There is no doubt that the -21 is a much more attractive powerplant than the basic CJ-805-3. The -21 is well matched to aircraft cruising at between M 0.8 and 0.9, at which speed the jet/aircraft velocity ratio is about 1.7 : 1. Without augmentation it produces 35 per cent greater take-off thrust and from 8 to 12 per cent lower cruising specific consumption; in addition, it is amenable to thrust reversal and has an exceedingly low inherent noise level. The installed engine (assuming a pylon-mounted nacelle) can have a short-cowl annular inlet for the fan air, lateral inlets, or a common pitot intake in the nose and a fat cowling throughout; the last arrangement has been adopted in the CV-600. Momentum drag is bound to be fairly high, and what G.E. have really done is to produce a bigger engine than the basic turbojet.

Reference: December 26, 1958.

T58 Since 1954 this small turboshaft engine has been developed under Navy sponsorship as the first major assignment of the Small Aircraft Engine Department at Lynn, Mass. Like the big J79, this engine has variable stators over a considerable portion of the compressor and this is one of the principal keys to its outstanding performance. In the air the T58 is operated at substantially constant r.p.m., and automatic systems have been evolved to control two or more engines tied to a single helicopter rotor.

Bench testing began in April 1955. The first 50 hr pre-flight rating test was completed in the early summer of 1957, and T58s have now flown in the Sikorsky S-62, Vertol H-21D, Sikorsky HSS-1F (S-58) and in a Westland Whirlwind. More than 13,000 hr has been run on the bench, and by the end of the year it is anticipated that the T58 will be flying in five further types of aircraft (S-61, Vertol 107, Kaman K-16 and HU2K and Fairchild M-224) and will have accumulated more than 22,000 hr running—and 45,000 hr should have been logged by the end of next year. Outside the U.S.A. the engine is being handled by D.H. Engines, who are developing a range of variants as the de Havilland Gnome (*q.v.*). American T58s are at present being sold for around $55,000.

Reference: Jan. 17, 1958 (full history, description and G.E. cutaway drawing).

T64 Since 1955 the Small Aircraft Engine Department have been busily engaged in developing this versatile turboshaft engine against a long-term contract valued at no less than $58.5m. The contract specified a turboshaft engine and a turboprop both utilizing the same power section. The initial rating is 2,600 s.h.p. and the weight (presumably without reduction gear) will be about 700 lb. A contract price of $78,500 was quoted for the turboprop and the helicopter version last year. No further information has become available on the development of this engine beyond that published in our July 26, 1957, issue.

HERRMANN *Herrmann Engineering Company, Glendale 1, California.* The Model 375 cam engine developed by the Herrmann Company holds an approved engine type certificate issued by the C.A.A. (now F.A.A.) valid for both helicopters and aircraft. Development is continuing at the pace appropriate to a small organization with limited resources but aircraft applications are still foreseen.

Reference: July 26, 1957, page 135.

LYCOMING *Lycoming Division of Avco, Stratford, Connecticut.* One of the world's foremost producers of small aircraft engines, Lycoming has never, except for a period during World War 2, been in the big-engine business. Instead, the company has concentrated on meeting the propulsive needs of utility-type aircraft and in recent years has played an outstanding rôle in the fields of helicopters, VTOLs and STOLs.

Gas Turbines

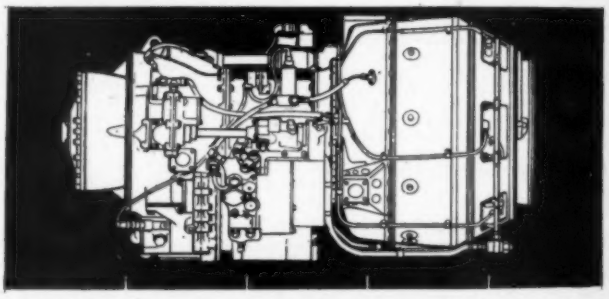
T53 After winning a joint U.S.A.F./Army competition in 1952, design began on the T53 or Model LTC1. Initially rated at 700 s.h.p., this was the first American free-turbine engine, and it became the first turboshaft engine for helicopters to go into production in America when quantity deliveries began early last year for the Army's Bell HU-1 Iroquois and the U.S.A.F.'s Kaman H-43B. It is also fitted to the new Army YHC-1 as well as the Doak Model 6 ducted-fan machine, the Ryan Model 92 deflected-slipstream aircraft and the Vertol Model 76 tilt-wing. Last year Lycoming applied for an F.A.A. certificate, and it is expected that this will be granted this year for commercial helicopter operations.

Current engineering developments are based on a high-speed growth version designated T53-L-5. This engine will be rated at 960 s.h.p. and will have reduced specific fuel consumption (0.696 lb/hr/s.h.p.) and will be some 20 lb lighter than the present version depicted in the illustration. The L-5 is scheduled for its 150 hr qualification test in November, with deliveries to begin early next year. A virtually identical engine is the L-3 turboprop, likewise rated at 960 s.h.p., which has been under development for the Grumman AO-1 Mohawk since July 1957. Apart from the reduction gearing, the L-3 and L-5 are virtually identical: the turboprop's 50 hr preliminary flight rating test was passed in June last year, the full 150 hr qualification is imminent, and flight trials of the AO-1 are due to begin very shortly.

Reference: Jan. 17, 1958 (history and full description).

T55 Following the same configuration as the T53, the T55 is rather larger and roughly twice as powerful. The first of this new family, the T55-L-1, was placed under contract in 1954 as a 1,500 s.h.p. turboprop. It completed its preliminary flight rating test in December 1957 at 1,600 s.h.p. At about the same time, the L-3 helicopter engine came into being with a rating of 1,850 s.h.p. One of these engines has been put through three successive 50 hr tests without any major parts replacement. As was the case with the T53 family, the uprated helicopter engine has been married with the gearbox of the turboprop to produce the L-1A turboprop rated at 1,850 s.h.p.

The next logical step was the high-speed L-5. This represents the basic T55 without any reduction gearing and with an integral oil tank and cooling system in the space which this component previously occupied. Three advanced versions are on the drawing boards which, while remaining in the same power class, offer better performance by employing an aerodynamically improved compressor.

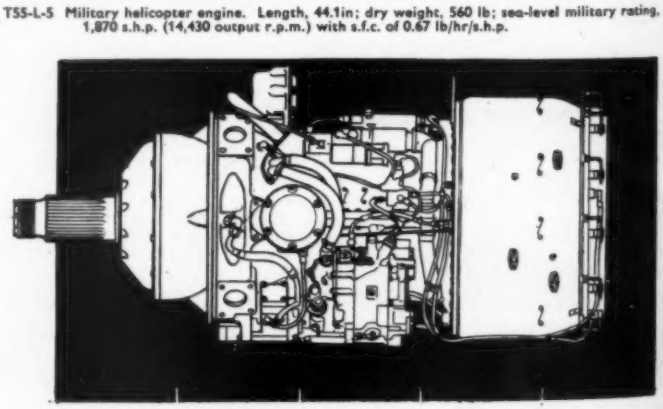


Lycoming LTC1K-1, T53-L-5 Military free-turbine helicopter engine. Compressor with five axial stages and one centrifugal stage, annular combustion chamber with 11 vaporizing burners, single-stage high-pressure compressor turbine and single-stage low-pressure power turbine. Overall diameter, 22.9in; length as depicted, 48in; dry weight, 460 lb; max sea-level rating, 960 s.h.p. (1,005 e.h.p.) at 6,610 output r.p.m. with s.f.c. of 0.696 lb/hr/s.h.p.

LTC1F-1, T53-L-3 Military turboprop. Length, 58.9in; dry weight, 495 lb; same rating as K-1 at 1,700 output r.p.m., with s.f.c. of 0.655 lb/hr/e.h.p.

Lycoming LTC4C-2, YT55-L-1A Military free-turbine turboprop. Compressor with seven axial stages followed by one centrifugal stage, annular combustion chamber with 14 vaporizing burners, single-stage, high-pressure compressor-turbine and two-stage low-pressure power turbine. Overall carcase diameter, 24.25in; length as depicted, 58.85in; dry weight, 695 lb; max sea-level rating, 1,850 s.h.p. (1,934 e.h.p.) at 18,660 compressor r.p.m. (1,410 output r.p.m.) with s.f.c. of 0.648 lb/hr/e.h.p.; mass flow and pressure ratio, about 20.5 lb/sec and 6.5:1.

LTC4B-3, T55-L-5 Military helicopter engine. Length, 44.1in; dry weight, 560 lb; sea-level military rating, 1,870 s.h.p. (14,430 output r.p.m.) with s.f.c. of 0.67 lb/hr/s.h.p.



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These engines are the L-7 high-speed turboshaft unit, the L-9 geared helicopter engine and L-11 turboprop.

Piston Engines

The company's line of reciprocating engines covers the power range 115 to 400 h.p. (excluding the Wright R-1820, which is produced by Lycoming for several military aircraft). Plans are in hand to extend the power of the company's own designs to 520 h.p.; several new models were introduced last year, including their first two engines with direct injection.

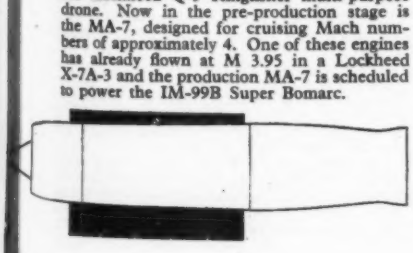
O-360 The company's first fuel-injection engine was the IMO-360-A1A flat-four rated at 180 h.p. This engine is in production as the standard power unit of the USD-2 target drone manufactured by Rheem for the U.S. Army Signal Corps. Weighing 251 lb, the IMO-360 is 34 lb lighter than the carburetted version. Announced last year but only just beginning to come off the production lines is the VO-360-A1A vertical-crankshaft engine for helicopters; the standard O-360 remains widely used in fixed-wing aircraft at the same standard rating of 180 h.p.

O-480 The company's second fuel-injection engine was the IGSO-480-A1A6. The ninth development in the O-480 family of geared six-cylinder engines, the IGSO-480 is, at 490 lb dry, 2 lb lighter than the carburetted version and has considerably reduced height and length. Rated at 340 h.p., it is in production for the 1959 Twin Bonanza.

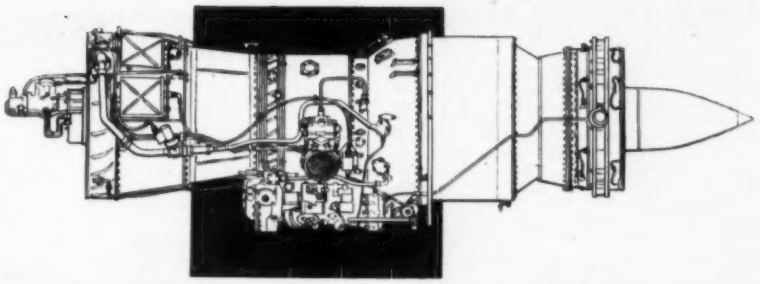
O-540 Two new models in the 540 cu in class were introduced last year. The first is the O-540-A1A rated at 250 h.p. with 8.5 : 1 compression ratio on 91/96-octane fuel. Within a few weeks of its initial announcement orders had risen to over $2m, chiefly for the Aero Commander 500 and the Piper Comanche 250. The counterpart for helicopters is the 310 h.p. VO-540-A1A, in production for the Hiller 12E.

MARQUARDT *Marquardt Aircraft Company, 16555 Saticoy Street, Van Nuys, Cal.* A history of this remarkable company was given in our July 26, 1957, issue and they remain the world's largest private firm specializing in ramjet propulsion. The most important production powerplant is that described and illustrated. The basic supersonic ramjet is now being scaled up and down and developed for flight at appreciably higher Mach numbers. Two of these new engines are known to be the RJ57 and RJ59; both are shrouded in U.S. Air Force security, although it has been reported that the RJ59 has been successfully flight tested in the Lockheed X-7A-2 and the company are known to have a U.S.A.F. contract for the MA-24, a 36in engine. The company are also active in the fields of engine accessories, auxiliary power units, afterburners and variable nozzles, ram-air turbines, turbo-rockets and nuclear-reactor turbojets, ramjets.

MA-20C Under this company designation Marquardt have evolved a family of supersonic ramjets with a diameter of 28in. Virtually all the controls and accessories are housed in the centrebody, which maintains a circular section of varying diameter right back to a bluff base in line with the flame holder. The version illustrated is in production—at a rate of at least eighteen engines per day—for the Boeing IM-99A Bomarc air-defence missile of the U.S.A.F. and R.C.A.F. This production powerplant was developed from the MA-1, which was extensively tested in XIM-99s and Lockheed X-7A-1 test vehicles. A recoverable engine, probably developed to give improved life characteristics, is the MA-5 which powers the Lockheed Q-5 Kingfisher multi-purpose drone. Now in the pre-production stage is the MA-7, designed for cruising Mach numbers of approximately 4. One of these engines has already flown at M 3.95 in a Lockheed X-7A-3 and the production MA-7 is scheduled to power the IM-99B Super Bomarc.



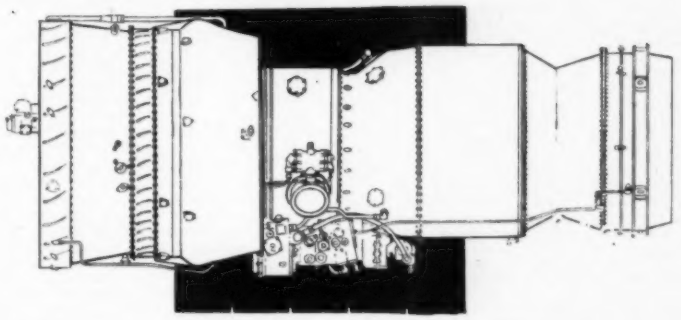
Marquardt RJ43-MA-3 Military fixed-geometry ramjet. Double-shock annular intake, concentric rings for fuel injection and circular flame-holder at downstream end of centre-body, con-di nozzle. Overall diameter, 28in; length, 140in; design Mach number, 2.5; other data restricted.



Pratt & Whitney JT3C-6 Commercial two-spool turbojet. Nine-stage low-pressure compressor, seven-stage high-pressure compressor, combustion chamber with eight annular flame tubes each having six burners, single-stage high-pressure turbine and two-stage low-pressure turbine. Max diameter of carcase, 38.88in; max height of engine, 49.2in; length as depicted, room temp., 138.64in; dry weight, 4,234 lb; max rating at sea level, 13,000 lb (s.f.c., 0.90) at 8,000 r.p.m. with water injection or 11,200 lb dry; corresponding mass flow and pressure ratio, 180 lb/sec and 13:1; normal rated climb thrust, 300 kt, sea level, standard day, 7,800 lb; max cruise, M 0.85, standard day, 4,850 lb (s.f.c., 0.963) at 20,000ft, 4,350 lb (s.f.c., 0.945) at 25,000ft, 3,820 lb (s.f.c., 0.938) at 30,000ft and 3,220 lb (s.f.c., 0.923) at 35,000ft.

JT3C-7 Similar configuration. Max diameter of carcase, 38.8in; max height of engine, 48.9in; length as depicted, room temp., 136.77in; dry weight, 3,495 lb; max rating at sea level, 12,000 lb (s.f.c., 0.785) at 8,000 r.p.m. without water; normal rated climb thrust, 300 kt, sea level, standard day, 8,450 lb; max cruise, M 0.85, standard day, 5,350 lb (s.f.c., 0.957) at 20,000ft, 4,770 lb (s.f.c., 0.932) at 25,000ft, 4,120 lb (s.f.c., 0.922) at 30,000ft and 3,550 lb (s.f.c., 0.909) at 35,000ft.

JT3C-2 (J57-P-43W) Military engine, same configuration. Max diameter of carcase, 38.6in; max height of engine, 49in; length with tailcone, room temp., 167.33in; dry weight, 3,840 lb; max rating at sea level, 13,750 lb (s.f.c., 0.95) at 8,000 r.p.m. with water. The P-43W is fitted to the KC-135 and B-52G.



Pratt & Whitney JT3D-1 Commercial turbofan. Two fan stages followed by six low-pressure compressor stages on the same shaft, seven high-pressure compressor stages, combustion chamber with eight annular flame tubes each having six burners, single-stage high-pressure turbine and three-stage low-pressure turbine. Max diameter of carcase, 53.05in; other dimensions not stated but the drawing is accurate and can be scaled; dry weight, 4,025 lb; max rating at sea level, 16,000 lb (s.f.c., 0.61); normal rated climb thrust (max cont.), 300 kt, sea level, standard day, 9,820 lb; estimated max cruise, M 0.82 (note: JT3C figures are given at 0.85), 35,000ft, standard day, 4,420 lb (s.f.c., 0.765); under same conditions 4,000 lb gives s.f.c. of 0.784 and 3,250 lb gives s.f.c. of 0.777. These figures are based on bench testing at the Willgoos high-altitude laboratory.

PRATT & WHITNEY *Pratt & Whitney Aircraft, Division of United Aircraft Corp., East Hartford 8, Connecticut.* During the past year this great company—generally recognized as the largest single aero-engine manufacturing firm in the world—has maintained its policy of increasing diversification. Faced with the final dwindling of the once-vast piston-engine production lines, Pratt & Whitney are supplementing their secure gas turbine business with sorties into the fields of ramjets, rockets and nuclear power.

Ramjet work has been in hand at the main plant at Hartford for ten years, but little hardware seems to have emerged and no information is available on current work. Rockets have only recently engaged the company's attention. It was rumoured last summer that work of this nature was in hand at the new plant at West Palm Beach, and confirmation came in November when the U.S. Air Force announced the award of a $9m contract for a new liquid-propellant rocket engine. No details are available of this unit beyond the fact that it will employ a high-energy propellant combination (liquid oxygen and liquid hydrogen, perhaps) and will power the upper stage of the two-stage Atlas satellite launching vehicle authorized by the ARPA.

In the nuclear field Pratt and Whitney were teamed as engine builders with Lockheed Aircraft (Georgia Division). The two companies were one of the combines working on the WS-125 nuclear-powered bomber specification, and the Pratt & Whitney effort was concentrated at the CANEL establishment on the Connecticut River. The engine was to be a closed-cycle unit associated with a turbojet designated J91, and notes on this programme were contained in our July 26, 1957, issue, pages 138-9. During the past year the work has decelerated considerably and CANEL is not now working at anything like the rate originally visualized. It appears likely that the closed-cycle engine will not be proceeded with.

JT3/J57 Since its design began in 1948, more effort has been applied to the engineering, development and mass production of this high-pressure turbojet than to any other American aero engine. Originally heavy, complicated and expensive in relation to the power developed, it has been progressively refined until in its latest production versions—which are virtually scaled-down JT4s—it compares favourably with engines developed by other manufacturers. The J57 has always been renowned for its reliability and moderate to good specific fuel consumption, and it is today in widespread service in supersonic fighters, heavy bombers, tankers, carrier-based attack aircraft, cruise-type missiles and large airliners.

Bulk production of the military J57 started in 1953, chiefly for F-100s and early B-52s. These J57-P-1, P-3 and P-7 engines were rated at 9,500 to 10,000 lb dry, were constructed largely of steel and, depending on the installation, could be fitted with a two-position after-

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burner of various configurations giving from 30 to 50 per cent reheat augmentation. To meet the needs of the production programmes of the many types of aircraft powered by the J57, a second-source production line was established at the East Wacker Drive, Chicago, plant of the Ford Motor Company. This facility, together with Pratt & Whitney's main plant in Hartford, have now delivered approximately 15,000 engines to the U.S.A.F. and Navy. Production is now running at a reduced rate.

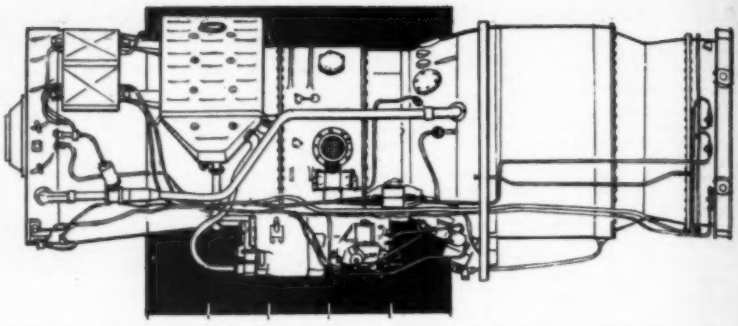
Current production J57s differ in almost every component from their predecessors of four years ago. Most of the modern powerplants have low-pressure compressors in titanium alloys, and the overall configuration of the engine has been cleaned up and brought into line with the more advanced standards established by the larger JT4/J75. Data for two typical military engines, the JT3C-2 (J57-P-43W water-injection engine of the B-52G bomber) and the JT3C-21 (J57-P-16 and P-55 afterburning engines of the F8U-2 Crusader and supersonic Air Force fighters) are given in the appropriate data panels.

Such modern combat variants have an appreciably higher fuel flow than the earliest J57s which, in conjunction with high-rate water injection, provides increased thrust at the expense of poorer specific fuel consumption. Dry weight of current military engines is of the order of 400 lb below that of the first models. Most of the recent fighter J57s operate on a cycle of around 200 hr, but the less arduous conditions encountered by the big aircraft of Strategic Air Command have permitted the authorized overhaul period to be increased to a current figure of 1,400 hr on both B-52s and KC-135 tankers. Engines fitted to B-52s have on occasions flown 1,000 hr without being removed from the airframe, and the 99th Bombardment Wing exceeded 200,000 engine flight hours (on J57-P-19Ws) without sending an engine off the base.

References: Nov. 27, 1953; May 14, 1954.

JT3 Commercial In turning the established J57 military engine into an airline powerplant, Pratt & Whitney had to meet previously unparalleled standards of reliability and safety, and the C.A.A. (now the F.A.A.) required the company to demonstrate exceptional performance in such matters as integrity in the overspeed condition, protection against icing, ingestion of foreign objects, operation on contaminated fuels and fuel-system behaviour under a range of temperatures from −65 to +300 deg F. An approved commercial type certificate was issued for the JT3 on March 14, 1957, and the first version to enter commercial service, the JT3C-6, went into transatlantic fare-paying operation with PanAm on October 26 last.

As might be expected, the C-6 is the final commercial development of the first generation of JT3 engines, and data are given in a panel beneath the appropriate drawing. In Boeing 707s and Douglas DC-8s it is equipped with various types of starter (usually fuel/air) driving the high-pressure assembly, together with full compressor-bleed de-icing, a high-flow bleed duct driving air-turbine compressors for cabin pressurization, reverser systems providing about 50 per cent negative thrust and fixed-area noise-suppressing nozzles. These engines are in service at an approved overhaul life of 1,000 hr, although it is too early yet to predict what proportion of engines will reach this figure.



Pratt & Whitney JT4A-3 Commercial two-spool turbojet. Nine-stage low-pressure compressor, seven-stage high-pressure compressor, annular combustion chamber with eight flame tubes each with six burners, single-stage high-pressure turbine and two-stage low-pressure turbine. Max diameter of carcase, 44.2in; overall length as depicted, 150.5in; dry weight, 5,125 lb; max rating at sea level, 15,500 lb. Other data are restricted.

JT4A-10 Similar, except for substitution of titanium for steel in the compressor and a thorough programme of weight reduction. Dry weight, about 4,200 lb; max sea-level rating, 16,500 lb.

J75 These military engines are rated at 15,500/18,000 lb dry and at 24,200/26,000 lb with reheat.

In September of this year deliveries will start on the C-7 engine, which is the first commercial model corresponding to the second-generation military engines. No less than 750 lb has been lopped off the weight, chiefly by re-stressing the engine to meet the reduced acceleration loads encountered in commercial operation, thinning the casings to meet the reduced internal pressures associated with wholly subsonic operations, eliminating water injection and alternative engine mounting provisions, using materials with improved strength/weight ratio and generally refining the design and incorporating advanced manufacturing techniques. Weight reductions have been particularly marked in such areas as the engine mountings, bearing supports, casings, compressor discs, flanges and portions of shafting. Better methods for sizing sheet metal and improving welding techniques have extended the range of materials available to include much finer gauges; sheet stock is now available to much closer tolerances than previously and structural efficiency in compound-curvature portions has been greatly improved by such processes as Flo-turning and chemical milling.

Elimination of the water system has reduced the maximum take-off rating fom 13,000 lb of the C-6 to 12,000 (at 60 deg F ambient in both cases). In all other areas the C-7 shows appreciably better performance (considerable data are given beneath the illustration) and the improvement in cruising thrust and specific consumption is marked. List prices of C-7s are believed to lie between $145,000 and $150,000.

At present there is scheduled to be one more major development in this line of commercial engines. The JT3C-10 will in all its essentials be a C-7 fitted with water injection to provide full wet ratings with minimum increase in weight (chemically pure and filtered water is used without any addition of methanol). The C-10 engine will be available in April 1960.

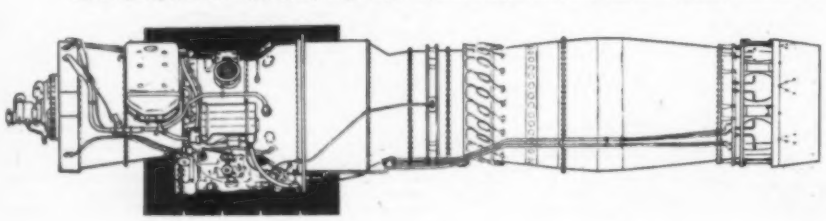
JT3D For a considerable period, and particularly since Rolls-Royce began to sell the Conway to the world's airlines, Pratt and Whitney have been well aware of the fact that the thrust/weight ratio and specific fuel consumption of the commercial JT3 family would have to be improved out of all recognition if the engine were not to be out-classed. After much deliberation it was decided to effect a modification so extensive as to produce virtually a new engine while yet remaining capable of being applied as a modification to powerplants already built. Essentially, the modification consists of substituting two large-diameter fan stages for the first three low-pressure compressor stages; enlarging the third stage turbine (i.e., the second stage of the low-pressure turbine) and adding a fourth stage to provide additional shaft power to drive the fan; and adding diffuser-case water injection. Starting with a JT3C-7, the conversion to the JT3D-1 turbofan can be accomplished at an overhaul shop, the new parts required including the fan stages and their casings, two turbine stages and their casings, a strengthened low-pressure shaft and a revised accessory gearbox mounted slightly farther aft than previously.

Extensive tunnel testing led Pratt & Whitney to evolve an installation with a direct ram intake of large diameter leading back to a nacelle of approximately circular section around the fan outlet; aft of this point the fan air is discharged through separate lateral ducts, the rear part of the nacelle being of elliptical section and tapering off to a relatively small jet nozzle aft. Nearly half of the D-1's thrust is developed by the fan. The overall conception is a sound one, and represents a serious attempt to produce a good commercial powerplant. Its worst faults are probably the fact that the installed engine must suffer from fairly high momentum drag during take-off, that for optimum efficiency the turbine inlet temperature should probably be higher than Pratt & Whitney's experience allows, and that the three propulsive nozzles are not readily amenable to thrust-reversal systems. From the point of view of noise, however, the engine is a distinct improvement on the simplest jet, a reduction of 10 db at full thrust at sea level being claimed. Bench running of complete JT3D-1 fan engines began last year; prototype engines will be available early in 1960 and production deliveries at some $195,000 are scheduled to start the following November.

JT4/J75 In order to meet the propulsive requirements of the advanced supersonic interceptors of the U.S. Air Force and Navy, Pratt and Whitney Aircraft produced the JT4 in 1951-54 to be the most powerful turbojet available in the United States. While adhering closely to the proven configuration of the JT3, the larger engine is much improved both mechanically and aerodynamically, and its increase in thrust is greater than the increment in bulk and weight would suggest. As already noted, the latest engines in the JT3 family are virtually scaled-down JT4s.

Several types of military J75s are in production at East Hartford, some engines having compressors of titanium alloys and some of steel. Most of the engines so far produced are of the sub-types J75-P-3 and P-5, these

Pratt & Whitney JT3C-21 (J57-P-16 and P-55) Military two-spool turbojet with afterburner. Basic configuration as for JT3C-6. Max diameter of carcase, 39.6in; max height of engine, 48.6in; length as depicted, room temp., 267.2in (P-16) or 250.84in (P-55); dry weight, 4,751 lb; max rating at sea level, with reheat, 16,900 lb (s.f.c. 2.30).



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being fitted to the Convair F-106 and Republic F-105 families. Both engines are equipped with variable afterburners and are stressed for flight at Mach numbers slightly greater than 2. Now coming into production is the J75-P-10, in which detail refinements and improvements in material specifications permit an increase in turbine inlet temperature and a slightly greater mass flow. This engine will be fitted to future F-106s and to the F-105D and E. A rather different unit is the J75-P-2 Navy engine, for the Martin P6M-2 SeaMaster.

JT4 Commercial Most of the Boeing 707 and Douglas DC-8 airliners so far ordered will be powered by Pratt & Whitney JT4 commercial engines. The version currently in production for the domestic and international DC-8s and the Boeing 707-220 and 320 series is the JT4A-3, corresponding roughly to the P-3 military engine and having a dry rating of 15,500 lb. This engine was awarded an approved type certificate in 1957 and is scheduled to go into commercial service later this year. The price is of the order of $245,000. The A-3 is now flying in both 707s and DC-8s and is reported to be performing well in these aircraft.

By 1961 deliveries should begin of the advanced JT4A-9, corresponding roughly to the J75-P-10. As in the case of the military engine, an increase in flame temperature and mass flow permits a considerable increase in both dry and wet ratings, and maximum sea-level thrusts of approximately 19,000 lb are at present being assumed for the A-9 in current DC-8/B.707 brochures.

JT8/J52 Developed originally to a Navy specification, this engine again adheres to the established J57/75 formula but is scaled down to give an initial thrust of 7,000 to 7,500 lb. Several versions have been planned, both with and without afterburners and with different accessory configurations. The original application—an advanced version of the Douglas A4D Skyhawk—did not materialize, but a considerable quantity of military J52s will be required by the Grumman A2F-1 multi-purpose carrier-based aircraft and the North American GAM-77 Hound Dog air-to-surface missile. In the Hound Dog the J52 will provide cruise propulsion at high subsonic and supersonic speeds over a range of at least 450 miles.

A commercial derivative of the JT8 family has been planned and it is logical to assume that a fan version is already under development. In fact, a pair of JT8 turbofans has been suggested as one of the most attractive propulsion systems for the short-haul jets at present being promoted by Boeing and Douglas. Such engines would probably give about 12,000 lb thrust for an installed weight of less than 2,500 lb and with a very good specific fuel consumption.

JT11/J58 Some three years ago Pratt and Whitney Aircraft started the detail design of a wholly new series of turbojets which promise to form a new generation of single-shaft engines as extensive and versatile as the JT3, 4 and 8 two-spoolers. The first of the new family is also the largest, and will probably remain so for several years to come. As the J58 it has been developed rapidly and successfully by the company's new research and development centre at West Palm Beach, Florida, under contract from the U.S. Navy.

It is the first American engine of which details are available designed for flight at Mach numbers of 3 or more. It follows the appropriate configuration in having a relatively low inbuilt pressure ratio but a tremendous mass flow per unit of frontal area; in fact, the engine can be thought of as a de Havilland Gyron designed to take full advantage of recent improvements in the state of the art. Internal details remain classified but the compressor apparently has nine stages, the first four being slightly separated by a circumferential bleed system, the shutters of which can be opened and closed by three actuators disposed around the casing in order to provide improved handling over the very wide range of flight conditions encountered. This is a much simpler arrangement than employing variable stators, and represents the logical outcome of the rudimentary bleed valves employed on the PT2F turboprop. The high-intensity combustion system appears to adhere to the company's established policy in having only eight burners; the turbine almost certainly has two stages and in its present form the engine is teamed with an afterburner of advanced design terminating in a huge con-di variable nozzle.

Already several versions have made their appearance, although the first experimental prototype only ran at the beginning of last year. Funding from the Navy is sufficient to have permitted the construction of a batch —suggested to be about 50—of prototype and development engines, and one of the first of these completed a very successful 50 hr test in August last year. An appreciable proportion of the current running time is taking place with high-energy fuels both in the afterburner and main combustion chamber. No engine of this family yet has an announced application, although twin J58s may power a new version of the Convair B-58.

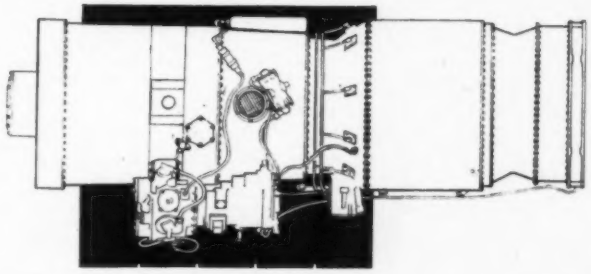
JT12/J60 Following upon the practice established with the JT3 family, Pratt and Whitney are starting to play tunes upon the basic geometry of the new generation of single-spool engines. It is fair to assume that the JT11 is the largest member of this new family, and it is equally likely that the JT12 will be the smallest for a considerable time to come. Pratt & Whitney have scaled this basic layout to the optimum size of engine for maximum thrust/weight ratio, and they have succeeded in reaching the excellent value of 7 : 1. As at present conceived, the JT12 is under development for military and civil applications involving such diverse fields as business and executive aircraft, military trainers, target drones and missiles. The fixed geometry of its single-rotor design, coupled with its outstanding brochure performance, has already placed it in a commanding position in the 3,000 lb thrust field (notwithstanding its appearance on the scene a full year after the Fairchild J83 and the G.E. J85).

An indication of the technical strength of Pratt & Whitney Aircraft is the timing of JT12 development: design studies begun, July 1957; detail design started, September 1957; drawings released, January 1958; first engine run, scheduled for July 1958, actually achieved May 16, 1958; 50 hr endurance test completed August 16, 1958. For unmanned applications prototype engines will be available in July and bulk production could start in June next year. For piloted aircraft, prototypes could be delivered in October and production deliveries are scheduled to begin in October 1960. Three of the first transport-type aircraft scheduled to use the engine are the Lockheed Jetstar, McDonnell 119 and North American T-39 Sabreliner. Essentially similar military J60 engines may be used by such aircraft as the Canadair CL-41 and possibly a developed version of the McDonnell GAM-72 decoy missile. With an afterburner, the advanced JT12A-20 is initially aimed at operation at flight Mach numbers of the order of 2, and with continued development is expected to reach Mach 3.

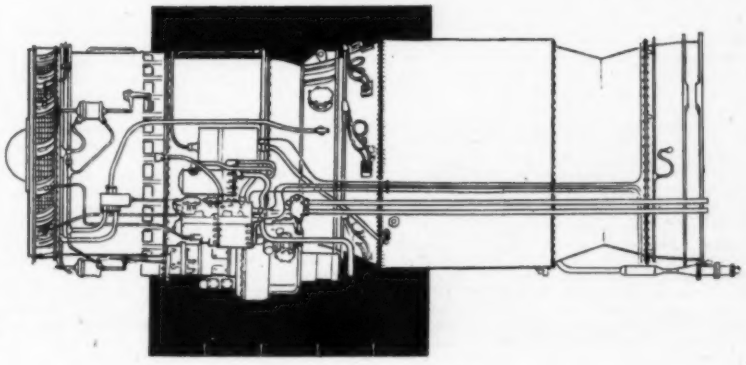
Pratt & Whitney have evolved a turbofan version of the JT12 which they are offering for use in projected airliners and executive aircraft. As far as is known, the engine exists only on paper, but unofficial reports state that the thrust would be approximately 4,000 lb and the weight about 600 lb. This could be the first single-shaft fan engine.

REACTION MOTORS *Reaction Motors Inc., A Division of Thiokol Chemical Corp., Denville, N.J.* In 1947 one of this company's first products, the 6000C4 four-barrel rocket engine, was the first aircraft powerplant to fly faster than sound. The vehicle was the Bell X-1, and derivatives of the 6000 series (military designation LR8) were used in all the X-1 aircraft. The pump-fed propellants of these four-barrel engines are liquid oxygen and a mixture of ethyl alcohol and water, and each of the regeneratively cooled

Pratt & Whitney JT8 (J52-P-1) Military (GAM-77 missile) two-spool turbojet. Nine-stage low-pressure compressor, seven-stage high-pressure compressor, annular combustion chamber with eight flame tubes each with six burners, single-stage h-p. turbine and two-stage l-p. turbine. Max carcase diameter, approximately 34 in; length as depicted, about 118 in; maximum rating, probably 7,500 lb thrust. The defunct J52-P-4 Navy engine for piloted (A4D-3) application was rated at 7,250 lb dry with s.f.c. of 0.8; the original J52-P-2, with afterburner, was rated at 10,000 lb. Most information on the JT8 family remains classified



Pratt & Whitney JT11 (YJ58) Military single-shaft turbojet. Axial compressor (almost certainly with nine stages), annular combustion chamber with eight flame tubes, two-stage turbine and large afterburner (not illustrated) with fully modulated con-di nozzle. All details are classified, apart from the fact that max dry thrust is "in the 30,000 lb class." It can be deduced that overall diameter is of the order of 50in, and dry weight is probably about 5,500 lb. Max thrust with afterburner (static at sea level) is likely to be about 45,000 lb.



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chambers has a sea level rating of 1,500 lb thrust.

LR11 Under this designation Reaction Motors have evolved a temporary stop-gap powerplant for the North American X-15 hypersonic research aircraft. The first two X-15s (and possibly the third aircraft) are each being equipped with two LR11-RM-5 rocket engines, mounted one above the other. The LR-11 is an advanced derivative of the LR8, running on liquid oxygen and kerosine fed by turbopumps from tankage which occupies the major part of the aircraft fuselage. All eight chambers are believed to be individually controllable to provide thrust variation, although presumably one of the engines would either be on or off as a unit and the other would be regarded as a vernier for fine control, perhaps during the approach and landing. Aggregate thrust of the complete installation is probably approximately 16,000 lb; this is not enough to explore the X-15's performance envelope fully but it permits the initial phases of the flight test programme to be undertaken with a relatively tried and proven powerplant.

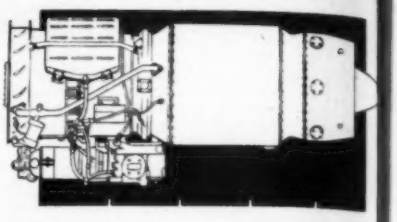
LR99 This is the ultimate engine which Reaction Motors are developing for the X-15. Few details of the XLR99-RM-2 have been released, beyond the fact that the rated thrust is in excess of 50,000 lb at sea level (a figure of 60,000 lb has been given unofficially) and that the propellants are liquid oxygen and ammonia. (These unusual propellants will be stored in the integral airframe tankage, which will be pressurized by helium gas to assist liquid expulsion.) The turbopump is driven by H.T.P., and delivers at engine manifold pressure at a maximum flow rate in excess of 10,000 lb/min. The LR99 has a single fixed chamber. XLR99s have been fired several times on the test stand, and should be delivered to North American before the autumn.

ROCKETDYNE *Rocketdyne, a Division of North American Aviation Inc., Canoga Park, California.* Since 1946 Rocketdyne have been one of the world's leaders in the design, development and production of large liquid-propellant rocket engines. The division's major facilities comprise the Neosho plant, Neosho, Mo. (production and production test), a propulsion field laboratory in the Santa Susana Mountains, Cal., and a components facility at Slauson (East Los Angeles) in addition to the main plant and head offices at the above address. Purchases last year totalled over $75m and on January 17 of this year the personnel total was 14,071: floor area includes 660,000 sq ft at Canoga Park and 224,000 at Neosho.

Although all the engines described below employ liquid oxygen and RP-1 hydrocarbon fuel as propellants, investigations have been conducted into other combinations, including fluorine and derivatives of hydrazine—such as Hydyne, the unique fuel employed in the first U.S. satellite launching achieved by the Army with a Jupiter C—and in 1956 Rocketdyne began intensive studies into ion propulsion. Sponsored by the Air Force, the latter studies are expected to result in space vehicles with outstanding performance; projected studies for the Moon and Mars were initiated in March 1957 and the first propulsive ion jets were generated at Santa Susana last August. In 1957 Rocketdyne received Air Force sponsorship for their work directed towards a nuclear rocket engine, thus accelerating a programme which had started in 1946. A major step-forward was the award last July of an Air Force contract for a single-chamber liquid-propellant rocket engine with a thrust of 1,000,000 lb; another engine, of some 600,000 lb rating, is being developed from design studies started in 1955. Rocketdyne's principal current units are described below; a back-up insurance engine for the N.A.A. X-15 aircraft has been cancelled. In addition, many hundreds of large rocket motors have been delivered for supersonic sled applications, the most important of these being the RS-1 and RS-2.

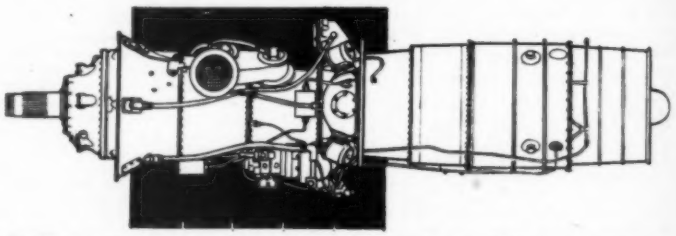
AR-2 Bearing the Service designation YLR42-NA-2, this is the only rocket engine present in the flight-test stage designed and developed for all-altitude boost propulsion of an American combat aircraft. Sponsored by the Navy, it is engaged in a test programme to determine the improvement in performance conferred upon the North American FJ-4 Fury, the FJ-4F having a single AR-2 above the turbojet nozzle. The AR-2 has a single fixed double-wall chamber fed with JP-4 or -5 and hydrogen peroxide by a turbopump energized by a gas generator. Combustion temperature is approximately 4,600 deg F but the thrust remains classified. Ignition is effected by the peroxide decomposition. The AR-2 contract was awarded in 1955 and the engine first flew on July 16 last year.

A-7 For ten years Rocketdyne have been engaged in the development and production of a series of liquid-propellant rocket engines for the U.S. Army medium-range Redstone ballistic missile and its derivatives. These engines originally owed much to the German A.4 (V-2) engine, and use similar propellants; they started bench trials in 1950, went into production in 1952 and flew in August 1953. The standard production engine is the **A-7**, illustrated. It is fitted to the M-5 Redstone MRBM, the Jupiter C test vehicle (modified to burn Hydyne) and the Jupiter C satellite vehicle (booster propulsion for the Explorer series). The A-family of engines were the first in the U.S.A. to enter production with a rating greater than 50,000 lb. It is worth noting that in the Explorer satellite launchings the single A-7 chamber in the first stage supplied over 98 per cent of the total effective impulse required; and the engine which placed Explorer 1 in orbit on January 31, 1958, functioned perfectly after being in storage for almost 14 months and was a 2½-year-old model.



Pratt & Whitney JT12A-3 Commercial single-shaft turbojet. Nine-stage compressor, annular combustion chamber with eight flame tubes and two-stage turbine. Overall diameter across flanges of intake, 18.79in; max carcase diameter, 21.9in; max height of engine, 27.8in; length as depicted, 74.2in; dry weight, 430 lb bare; max sea-level rating, 2,900 lb with s.f.c. of 0.928; max cruise at sea-level, 2,140 lb with s.f.c. of 0.890.

JT12-A-20 (J60-P-1) Military turbojet with afterburner. Configuration as above with addition of afterburner. Overall length, 126in; dry weight, 645 lb bare; max sea-level rating, 3,900 lb with s.f.c. of 2.30 or 1,800 lb at M 0.9 at 35,000ft or 3,650 lb at M 2.0 at 35,000ft or 1,400 lb at M 2.0 at 55,000ft; military rating, 2,830 lb with s.f.c. of 0.955; normal rated thrust, 2,350 lb with s.f.c. of 0.925. Without an afterburner the military J60 gives 1,800 lb with s.f.c. of 0.89 at 75 per cent power, and at 35,000ft at M 1.8 gives 993 lb with an s.f.c. of 1.17.



Pratt & Whitney PT2G-4 (T34-P-7W) Military single-shaft turboprop. Thirteen-stage compressor, combustion chamber with eight flame tubes and three-stage turbine. Max carcase diameter, 33.75in; max height of engine, 44.6in; length as depicted, 156.8in; dry weight, 2,670 lb; max rating at sea level (maintained to 100 deg F by water injection), 5,500 s.h.p. (6,000 e.h.p.) at 11,000 r.p.m. with s.f.c. of 0.63 lb/hr/s.h.p.; corresponding mass flow and pressure ratio, 67 lb/sec and 6.7:1.

PT2G-6 (T34-P-9W) Same configuration. Max carcase diameter, 34.06in; length, 155.12in; dry weight, 2,870 lb; max sea-level rating, 7,500 e.h.p. with s.f.c. of 0.55 lb/hr/s.h.p.

MA-2 Under this designation Rocketdyne have produced the complete propulsion system for the SM-65 Atlas ICBM developed by Convair for the U.S.A.F. Strategic Air Command. As described in our issue of December 5 last, this huge missile is powered by a centrally mounted sustainer engine and twin laterally disposed booster motors. All three engines draw liquid oxygen and RP-1 from the same tanks; all chambers are fired on the ground and the booster package is jettisoned after operating for its programmed duration.

Both chambers of the booster package are mounted on gimbals to provide coarse control of the trajectory during the launching phase. The boost engines are designated LR89-NA-3. Like the chambers used in the engines of the Jupiter and Thor IRBMs (which are of very similar design), the chamber of the LR89 incorporates an entirely new form of construction which significantly reduces weight and eases gimballing and flight-performance requirements considerably. This design of chamber was evolved during the original development of the rocket booster package for the Navaho cruise-ramjet missile.

The original Navaho engine was rated at 75,000 lb and was designed in 1951. Originally this powerplant embodied thick double-wall chambers regeneratively cooled by fuel circulated between the two shells. Engineering advances led to a completely new form of chamber, fabricated entirely from longitudinally disposed tubes (just as a barrel is built up from longitudinal staves). The production LR89 chamber is fabricated from approximately 300 nickel-alloy tubes, originally with an external diameter of 0.45in. These are pressure formed until their section becomes basically rectangular, varying in area from a maximum at the end of the tube near the nozzle of the chamber to a minimum at the throat. The tubes are positioned around a vertical jig, brazed together with silver solder and finally secured by welded circumferential steel bands to give the chamber bursting strength adequate for the very high internal pressure. The first engine incorporating tubular chambers was fired at Santa Susana in April 1953.

Work on the MA propulsion system for the Atlas began in March 1954, the original design being based on the experience gained with the Navaho package. The first flyable system was delivered to Convair in June 1956. The complete propulsion system, including the sustainer, was subsequently extensively ground tested by both Rocketdyne and Convair. The initial flight test was made in June 1957, using booster and vernier power only, and the first fully powered flight by an Atlas B, utilizing the centrally mounted sustainer in addition, took place on August 2 last year. Both of the LR89 chambers are gimballed to a common frame, and they are pivoted by a control system actuated by the guidance equipment. In the latest versions integrated tankage and turbopump systems are employed for all three chambers, and the boost package is enclosed in a chemically milled assembly of much reduced weight. The single LR105-NA-3 sustainer is designed to an expansion ratio appropriate to space flight, and supplies the slightly lower thrust necessary to sustain powered flight and keep the Atlas on course. It is similarly mounted on gimbals and is flanked by the multiple exhausts from the turbopump, and numerous venting and dumping systems. At the time of writing 22 Atlas test vehicles have been fired, including the Atlas Score satellite.

S-3 All the S-3 series are engines for the Jupiter IRBM, developed by the U.S. Army Ballistic Missile Agency at Huntsville and manufactured by the Chrysler Corporation

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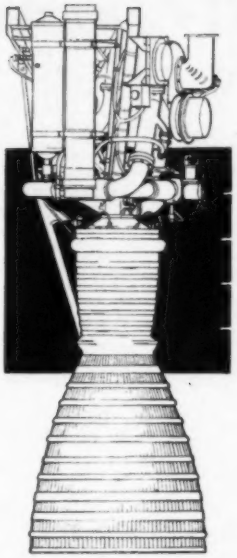
for overseas deployment by the U.S.A.F. Strategic Air Command. The chamber of this family of engines is very similar to that employed in the LR89 boosters of the Atlas ICBM, already described, and is identical to the chamber of the engine of the Thor IRBM (the MB-3, illustrated). Almost the only unique feature of the S-3 series is the manner in which the efflux from the gas generator, which drives the twin turbopumps, is expelled overboard from a swivelling nozzle which acts both as a vernier motor and as a roll controller during powered flight. Propellants are liquid oxygen and RP-1, and the specification is similar to that for the MB-3. The first engine was tested in November 1955, the mock-up was delivered in January the following year, production engines began to fly in September 1956 (an R. & D. unit was delivered the previous July), and the Jupiter started its flight-test programme in March 1957. S-3 engines have been fitted to all versions of SM-78 Jupiter IRBMs and to the NASA Juno space-probe vehicles (booster propulsion). The current S-3D is lighter and more compact than the earlier versions, and incorporates simplified starting and control systems. Features include the elimination of airborne starting tanks, a miniaturized pneumatic control panel, a thrust control system and engine-mounted hydraulic systems.

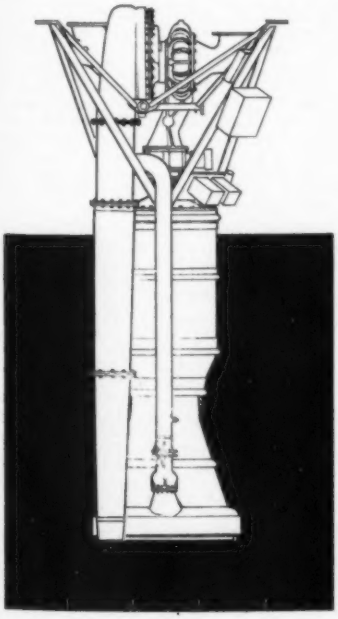
MB-3 Almost identical with the S-series of engines for the Jupiter, the MB-3 (Service designation LR79-NA-9) is in quantity production at the main plant in Neosho and is fitted to the SM-75 Thor IRBM of the U.S.A.F. Strategic Air Command and R.A.F. Bomber Command, to the U.S.A.F. Thor-Able test vehicle (booster propulsion) and to the ARPA Discoverer lunar-probe vehicle (boost propulsion). In all these vehicles the chamber is gimbal-mounted, and is flanked by vernier engines, forming an integral part of the propulsion system, which provide roll control and establish the final velocity and directional control after shut-down of the main engine. The exhaust-thrust from the turbopump gas-generator is slightly less than that of the vernier system and is discharged from a fixed downward-facing pipe flanking the main chamber.



Rocketdyne MB-3 (XLR79) Military rocket engine. Single gimbal-mounted chamber fed by turbopumps with liquid oxygen and RP-1. Chamber nozzle diameter, approximately 47in; overall height of package as depicted, 144in; dry weight, of the order of 2,000 lb; sea-level thrust at full propellant flow, 150,000 lb; propellant consumption, approximately 550 lb/sec.

Work on the MB-3 propulsion system began a few weeks after the Air Force received authority, in November 1955, to produce an IRBM. The first engine of the related Jupiter series was fired in November 1955, a research and development model was delivered for missile-mating firings in June 1956, and the first production model was shipped to Douglas in September 1956. Thor entered the flight-test stage in January 1957, and at the time of writing more than 30 rounds have been launched. Major engine components have been reduced from 46 in the early configurations to 28 in the current NA-9 models now being delivered. This achievement stems largely from a simplified starting and control system, which eliminates the airborne starting tanks and utilizes a miniaturized control panel. A slightly earlier version of the engine, incorporating airborne starting tanks, is depicted in the drawing.

Rocketdyne A-7 Military rocket engine. Single fixed chamber fed by turbopump with liquid oxygen and alcohol. External diameter of chamber nozzle, about 33in; overall height of package as depicted, approximately 115in; dry weight, of the order of 1,700 lb; sea-level thrust at full propellant flow, 75,000 lb; propellant consumption, approximately 300 lb/sec.



SOLAR *Solar Aircraft Company, San Diego 12, California.* For more than ten years Solar have been active in the field of gas turbines of diminutive proportions. Some thousands of units have been sold, the most common being the 50 h.p. Mars and the 500 h.p. Jupiter, both of which are widely employed in ground and marine applications (particularly in airborne auxiliary power units). The engine described below is the first to be planned specifically for aircraft propulsion.

T62/66 Titan Introduced in the spring of 1958, this extremely attractive unit is possibly the smallest aircraft engine in the world, and certainly one of the smallest gas turbines. It replaces the Mercury described in our 1957 review, and is being developed under a contract funded jointly by the Navy Bureau of Aeronautics and the U.S. Army.

The basic engine, the configuration of which is given in the data panel, has a centrifugal compressor and a radial inflow turbine mounted back-to-back with a bearing support between them. Hot exhaust gases are kept away from the external surfaces of the engine, and although turbine-inlet temperature is approximately 1,450 deg F no portion of the outside of the engine exceeds 450 deg F. Reliability and the need to minimize cost were dominant factors in the design. One of the chief problems encountered in the development of the Titan was the need to "custom-design" all controls and accessories, those previously on the market being disproportionately large. Most of the accessory and control systems had to be designed by Solar to a new standard of miniaturization, and starting is accomplished by a hand crank.

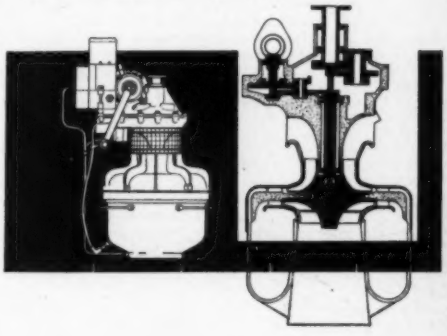
The engine is being developed in two quite distinct forms. The YT62 is a single-shaft version designed principally for one-man helicopters. The YT66 is a free-turbine model intended for use in flying platforms, the turbine wheel being divided into two sections to provide independent variation of compressor speed and output r.p.m. Pre-flight testing of a YT62 is at present taking place with a unit installed in a one-man helicopter (photograph, February 6, page 176).

WESTINGHOUSE *Aviation Gas Turbine Division, Westinghouse Electric Corp., Kansas City, Missouri.* Since 1941 this huge company has been actively developing axial turbojets, chiefly under contract to the U.S. Navy. One of their earliest designs, the 24C or J34, has proved to be their only real success; the larger J46 and J40 are now out of the picture (the former is in limited service in F7U Cutlasses), and neither of the engines produced as a result of the 1953 agreement with Rolls-Royce has found a production application. The latter engines are the XJ54 turbojet—virtually a scaled Avon 200—rated at 6,700 lb dry thrust, and the XJ81 turbojet rated at 1,800 lb and used in the Radioplane XQ-4 target drone. The agreement with the British company expires in 1961.

J34 Some thousands of these reliable single-shaft turbojets are in service in the McDonnell F2H Banshee and other aircraft. Production had ceased when, in 1956, Westinghouse received a contract to develop a new version tailored to the arduous requirements of the Navy's North American T2J-1 multi-purpose trainer. The production contract, worth $26m and awarded in November 1957, came as a welcome shot in the arm, and further "product-improvement" contracts have since followed. The T2J engine is depicted on p. 412, and it differs in having a new compressor, a revised combustion chamber and fuel system to permit unrestricted operation on JP-4 or JP-5 fuels, and in the arrangement of its accessories.

WRIGHT *Wright Aeronautical Division of the Curtiss-Wright Corp., Wood-Ridge, N.J.* For a variety of reasons, this great company have failed to retrieve their position in the field of aircraft propulsion. Current business is centred almost entirely upon the J65 turbojets, of basically British design, and upon the provision of spares and service-support for Turbo-Compounds. Later turbojets, turboprops, ramjets and rockets have all failed to achieve production applications. Notes on the J65 are given on p. 412. The Turbo-Compound, now out of production, is in world-wide civil and military service and has logged many millions of hours, yet its mechanical complexity and the arduous operating conditions of the power-recovery turbines and other portions is such as to make really long overhaul life and trouble-free operation an unattainable goal. The last batches of EA-series engines were priced at around $90,000 and are currently operated to an overhaul cycle of around 1,400 hr. The military-sponsored T47, T49, J67, XRJ47,

Solar YT62 Titan Military turboshaft engine. Configuration as shown in section drawing. Maximum carcase diameter, 12.5in; overall height, as depicted, 21in; dry weight, 50 lb; max rating, sea-level, at 56,700 r.p.m., 55 s.h.p. plus 12 lb thrust at 100 deg F rising to 70 s.h.p. in low ambient temperature.



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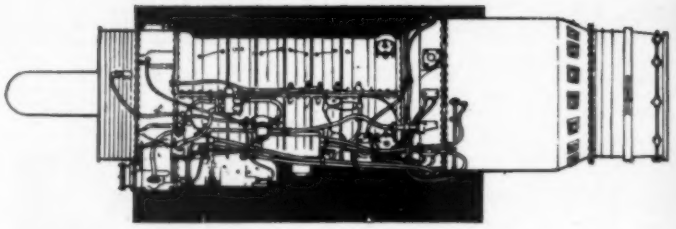
XLR25 and the XF-103 dual-cycle unit are all dead, and it appears unlikely that much more will be heard of the Wright-sponsored TJ-37 (Orpheus) and TJ-38 Zephyr (Olympus).

J65 Some 12,000 of these fine single-shaft turbojets have now been delivered, a proportion at one time coming from the Buick division of General Motors. Most J65s are rated at 7,220 or 7,800 lb, and are used in B-57s, F-84Fs, FJ-4s and A4Ds. An afterburning version rated at 10,500 lb is used in the F11F Tiger and in the XF-104s. Details of this engine were given in our last engine-review issue. What is probably the last J65 contract was signed by the Navy at the beginning of this year, for an improved powerplant matched to the A4D-2N Skyhawk.



Westinghouse J34-WE-46 Military single-shaft turbojet. Eleven-stage compressor, annular combustion chamber with two concentric rows of burners (total 60) and two-stage turbine. Overall carcase diameter, 32in; max height of engine, 35.5in; length as depicted, 115in; dry weight, 1,210 lb; max rating, 3,400 lb at 12,500 r.p.m., with s.f.c. of 1.0 and mass flow and pressure ratio of 59.5 lb/sec and 4.1:1.

U.S.S.R.

A STEADY trickle of information on Russian military and commercial engines has now provided sufficient information for a brief assessment to be made of the more important types currently in service. These are listed below.

Gas Turbines

AI-20 Probably working in competition with Kuznetsov's team which developed the NK-4, a design bureau under the leadership of A. G. Ivchenko has evolved a new turboprop with this designation. Their engine is clearly of more advanced design than Kuznetsov's NK-4. Practically no details are available, although it can be deduced that the AI-20 is a small-diameter axial of high pressure ratio, and it is likely to be a two-spooler. The AI-20 is at present rated at 4,000 s.h.p., is the standard powerplant of the An-10A and is scheduled to replace the NK-4 in later versions of the Il-18. It is matched with a four-blade propeller of 14ft 9½in diameter with a very large spinner and hollow steel blades.

Kuznetsov This designer is responsible for the 5,100 s.h.p. turboprop which powers the An-4 military assault transport. No details of the engine are available, beyond the obvious facts that it is an axial and drives a large, four-blade propeller.

LU-4 At least two Soviet reports have given this as the designation of the axial turbojet, designed by A. M. Lyul'ka, which powers the four-engined Tu-110 airliner. No details of the engine are available, but it is reported to have a maximum rating of 11,455 lb.

M-209 Bench trials of this big single-shaft turbojet must have started in 1952 at the latest, and at that time it was probably the most powerful engine in the world (in the absence of the defunct J53). Designed by a team led by A. A. Mikulin, the basic M-209 has an eight-stage compressor, a can-annular combustion chamber and a two-stage turbine. A cutaway drawing appeared in our issue dated July 26, 1957 (p. 142). Flight development took place with engines mounted beneath Tu-4s and accelerated appreciably when the Tu-16 "Badger" medium bomber started flying. The M-209 is the standard powerplant of the latter aircraft. Estimated thrust of the first versions in service with Tu-16s is 18,000 lb. An advanced version, rated at approximately 20,500 lb is believed to power the four-engined "Bison" heavy bomber.

NK-012, NK-12 Extensive details of this very impressive single-shaft turboprop, together with a cutaway drawing, were given on p. 143 of our issue dated July 26, 1957. Designed at Kubishev by a team consisting chiefly of ex-Junkers engineers led by the Russian W. D. Kuznetsov, the NK-12 family is by far the largest turboprop in the world. It adheres to design philosophies which are today outmoded; although the design pressure ratio is no less than 13:1, the compressor has 14 stages on a single drum and is driven by a five-stage turbine. To ease handling, the compressor is equipped with at least one row of variable-incidence guide vanes at the intake end, together with several blow-off valves. A can-annular combustion system is used, with 12 flame tubes. The reduction gear is mounted concentrically within the intake and provides shafts for driving contra-rotating propellers, each four-blade unit having a diameter of 18ft 4in.

Some hundreds of NK-12s must have been delivered as the standard powerplant of the Tu-95 "Bear" heavy bomber. A commercial version of the engine has also been evolved—probably differing but little in detail—for the Tu-114 and Tu-114D long-range transport aircraft. Maximum rating of all these engines is of the order of 12,000 s.h.p. at 9,250 r.p.m.; at 36,000ft at 565 m.p.h. and with turbine inlet temperature of 1,150 deg K, the maximum rating is no less than 8,000 s.h.p. with an s.f.c. as low as 0.353 lb/hr/s.h.p.

NK-4 Few details are available of this exceptionally attractive turboprop, which has been produced by a design team led by W. D. Kuznetsov. It is almost certain to be a single-shaft engine, probably with an axial compressor of at least twelve stages and an annular combustion chamber. The diameter of the rotating assembly is exceedingly small and the maximum r.p.m. are correspondingly high at 15,000. In the prototype and first production version of the Il-18 Moscow four-engined transport the NK-4 is arranged as a neat interchangeable power package, complete with an AB-68B four-blade propeller with a diameter of 13ft 8½in. The maximum rating of the Il-18 engine is 4,000 s.h.p.

RD-3, AM-3 One of the most highly developed large turbojets in the world, this commercial engine is the transport derivative of the well-known M-209 already described. It probably powers all variants of the Tu-104.

The first version to go into service has an eight-stage compressor, a can-annular combustion chamber and a two-stage turbine. An electric starter is fitted in the nose bullet, accessories are grouped uniformly around the compressor casing, and compressor air can be bled for heating the intake and providing air for cabin pressurization and airframe de-icing. Overhaul life is believed to be 400 hr.

The most common version, fitted to the Tu-104A, is the RD-3M which has been developed from the basic Mikulin engine by a team led by P. F. Zubets. The 3M is rated at 19,180 lb thrust and is reported to weigh 5,100 lb.

TB-2BM Very few details are available of this turboshaft engine, which has been evolved chiefly for rotorcraft and is the powerplant of the very large twin-engined Mi-6 helicopter. In this aircraft the engines are mounted side-by-side above the fuselage, the drive being taken out of the rear end of each engine through primary and secondary gearboxes and thence into the rotor shaft (a layout identical to that adopted for the Westminster). The TB-2BM is obviously an axial engine of relatively advanced design, and it is reliably reported to be a free-turbine unit. The team responsible is believed to have been led by Soloviev. The first two reports suggested that the engine has a maximum power of 4,700 s.h.p., but it is reliably reported that only 2,500 s.h.p. are at present available from each of the engines fitted to the Mi-6.

VK-1 As previously noted in these engine review issues, the VK-1 is a derivative of the Rolls-Royce Nene (itself mass-produced in Russia as the RD-45), prepared under a design team led by V. Ya. Klimov. Compared with the British engine and the RD-45, the VK-1 family have appreciably increased capacity, the mass flow being 110 lb/sec and the dry sea-level rating varying between 5,955 and 6,200 lb thrust. The VK-1A is equipped with a wholly Russian afterburner with a two-position clam-shell nozzle, giving a maximum reheat rating of 7,590 lb. Some 25,000 engines of this general family were manufactured between 1952 and 1956 for the Mig-17 and the later versions of the Mig-15 and Il-28.

VK-5? M-205? Both these designations have been suggested for the very attractive turbojet which powers two of the most important defensive aircraft in the entire Soviet military aviation forces, the Mig-19 "Farmer" and Yak-25 "Flashlight." Obviously an axial, and of commendably small diameter (of the order of 30 to 32in), the dry rated thrust of one version is given as 8,690 lb. Engines of approximately this rating are fitted to the various versions of the Yak-25 and similar engines, with a thrust given as 8,818 lb, are fitted to the twin-engined Mig-19. An afterburning version is known to exist.

Piston Engines

AI-4 An air-cooled, flat-four developed by A. G. Ivchenko, the current production version is rated at 55 h.p. and is fitted to the Kamov Ka-10 coaxial helicopter.

AI-14 A small nine-cylinder air-cooled radial, this Ivchenko engine has been made in large numbers and remains in production in two major versions; a fixed-wing variant rated at 240 h.p. is fitted to the Yak-12 series of liaison aircraft and a 225 h.p. helicopter version is mounted horizontally in the Ka-15 and Ka-18 coaxial helicopters. The fixed-wing version is in production in Poland.

AI-26 This is a seven-cylinder radial which is in production at a rating of 575 h.p. for the Mi-1 helicopter family. It is mounted in this aircraft with the crankshaft horizontal, and has fan cooling.

ASh-21 Numerous versions of this seven-cylinder single-row radial have been evolved by A. D. Shvetsov from the American Wright R-1300. Many thousands of fixed-wing versions have been delivered for the Yak-11 series of advanced trainers; these engines are rated at 730 h.p. and drive a two-blade controllable-pitch propeller. A helicopter variant is also known to exist.

ASh-62 Many versions of this highly-developed nine-cylinder single-row radial have been evolved by the designer A. D. Shvetsov. Rated at 1,000 h.p., it powers the An-2 biplane in all its versions.

ASh-82 Developed by Shvetsov from the American Wright R-2600, this engine has been built in large numbers, principally for the Il-12 and Il-14 twin-engined transports. The latest fixed-wing versions are rated at 1,900 h.p. and are probably out of production in the Soviet Union, but remain in licence-production in Czechoslovakia (*q.v.*). As a helicopter powerplant the ASh-82V is of great importance. Rated at 1,700 h.p., this version is the standard powerplant of the big single-rotor Mi-4 and of the twin-engined, twin-rotor Yak-24.

M-11 Many thousands of these five-cylinder radials have been delivered for a variety of light aircraft and helicopters. One of the most common versions is the M-11FR, which powers the Yak-18 trainer family.

CORRESPONDENCE

The Editor of "Flight" is not necessarily in agreement with the views expressed by correspondents in these columns. The names and addresses of the writers, not for publication in detail, must in all cases accompany letters.

Three-axis Control Columns?

I CAN foresee a serious difficulty with the Coombs control stick ("Getting to Grips with the Stick," by L. F. E. Coombs, *Flight*, February 27). Because the fulcrum for the stick's lateral rolling motion is not directly below the handle the pilot's arm will have to support part of its own weight; if it doesn't, its weight, pulling down on the handle, will apply unintentional aileron deflection. In practice, this will rapidly become very wearying. The remedy is simply to put the fulcrum directly under the handle.

Speaking more generally, if pure powered controls are now permissible, with no manual reversion being provided, why not put all three control axes on the handle and eliminate the rudder pedals? The maximum number of things which can be controlled with one handle is six, so three should be easy. One might have: elevators, forward push-pull; ailerons, lateral push-pull; rudder, a twist grip on the vertical stick. This is only one of many possible combinations. The three-axis-by-hand systems have the advantage that the pilot's feet are free to operate brakes and/or ground steering while in the air they are no longer tied to one place but can be moved about a bit to ease fatigue.

Now that elaborate imitation aeroplanes are available (in the form of servo test-rigs or flight simulators which can have almost any desired type of response) it should be fairly cheap to set up such a control system and see how pilots like it.

Cambridge. C. W. McCUTCHEN.

B.E.A.'s Pool Agreements

FURTHER to the article "B.E.A.'s Competition" [*Flight*, February 20], I would like to comment on various points which the author makes in his summary (the eight paragraphs below correspond with the eight of the summing-up).

B.E.A. are not unique in operating in pool with so many of their rivals. K.L.M. operate in pool with ten of their European rivals, and Air France, Alitalia, Aer Lingus, Lufthansa, S.A.S. and Swissair are similarly committed.

It is not fair to say that as much as 95 per cent of B.E.A.'s traffic will be subject to little or no European competition. B.E.A. will have to sell even more intensively than ever before against their pool partners, and, having sold their space, will have to back the sales effort by better passenger-treatment in the spheres of handling, cabin service and crew attitude towards passengers. Goodwill is essential to good business; and good manners—even in difficult circumstances—make for both. The take-it-or-leave-it attitude and impersonal couldn't-care-less technique common to both British-flag carriers, which creates a lasting and unfortunate impression with first-time passengers particularly, will have to disappear if the Corporations are to win satisfied customers during the coming sales battles.

Certainly pool agreements are not often the subject of public announcements or press releases; but the fact that a service is operated in pool with another airline is mentioned in both the time tables of B.E.A. and those of its pool partners.

Economically, a pool agreement is not a cartel, but a practical means of eliminating many wasteful items of airline expenditure, such as fixed-charges (landing fees, handling charges, etc.) and inevitably leads to better fleet and crew utilization and improved load-factors. The commercial divisions (particularly on the sales and publicity side) of each airline concerned have to make an even greater effort to maintain sales at the increased level of production, even on a pool route. The European situation is quite different from the United States domestic problem. In spite of its smaller fleet units and series of routes radiating from each capital city (rather than a collection of transcontinental networks) the European traffic potential is greater than that of the United States, on account of the larger population of Western Europe.

B.E.A. are in a unique position in that they are not strictly long-haul operators, unlike the majority of their pool partners which operate services to other continents. On paper, Aer Lingus is the one exception to this, but, in fact, Aer Lingus and Aerlinte are commercially one and the same organization. The extraordinary and paradoxical situation is the relationship between B.E.A. and B.O.A.C, which give the impression that they are two competing and deadly foreign rivals, rather than two airlines sponsored by the same country. The financial agreements whereby B.E.A. have holdings in several European airlines, notably Aer Lingus and Alitalia, naturally lead to commercial association and to the ventilation of B.E.A. policy on the Boards of these companies.

The political arguments for pooling would appear to be to B.E.A.'s advantage as a State-owned corporation. Compared with Air France, for example, B.E.A. have to operate far more as a commercial organization than as a government department, especially in a financial sense. Naturally, B.E.A. have bargaining power, through the United Kingdom Government, by reason of the European traffic pattern into London particularly; yet it must be remembered that certain of the routes operated into European capitals were pioneered and developed by the national-flag carriers concerned—e.g. Amsterdam - London, Brussels - London, Western Germany - London—long before B.E.A. came on the scene.

On balance, it would appear that B.E.A.'s 13 pools bring greater political and commercial advantages than disadvantages, particularly in view of the recent "Big Five" Common European Market Airlines (Air France, Alitalia, K.L.M., Deutsche Lufthansa and Sabena) meeting in Brussels and the consortium envisaged by them. Whether this view of B.E.A. towards pool agreements is a permanent change in the thinking of socialized air transport or not, it is spotlighted by the recent Aer Lingus - Silver City pool agreement on the new Dublin - Blackpool route. It is, of course, nothing new for British private enterprise operators to run services in pool, as Hunting-Clan and Airwork have been doing so for years on their U.K.-Africa Safari services.

One of B.E.A.'s problems has been, and still is, to persuade the British public to fly by British European Airways rather than by British independent airline or by a foreign carrier. Pooling may perhaps be the solution to this. Whilst B.E.A. may not have thought pooling to be "the right commercial course" over a year ago, both the political situation (due to the European Common Market) and the commercial picture have altered radically during the last few months. Hence, a revision of thinking is timely if B.E.A. are to maintain and expand their contribution to the European pattern of commercial airline operations.

Dublin. LANGDALE SUNDERLAND.

Wooden Walls

THE cost to the United States of research on nose-cones for ballistic missiles is of the order of $500 million for present commitments alone. Two great new laboratories have been staffed with double-doctorate scientists, to do nothing else but investigate ever more exotic materials. In his always amusing column, your Mr. Roger Bacon (January 2) questioned the fact that in its first full-scale firing the Atlas used a lightweight steel honeycomb nose-cone instead of the heavy copper model scheduled for production. "Are we now to understand," he asked, "that the job can be done by something lighter and cheaper?"

Perhaps you noticed that *Aviation Week* capped this story by a report (January 26) that the Soviet ICBM uses a *wooden* jacket, which smoulders away "leaving the nose-cone relatively cool."

Connecticut. J. M. S.

Boeing 707 Incidents

WITH reference to articles which have appeared in your publication relating to two incidents involving Boeing 707 aircraft operated by Pan American, I would like to draw your attention to the following extract from *Aviation Daily* of February 19:—

"*Autopilot Reported Blameless in 707 Incident.* There was no malfunction of the autopilot of the Pan American 707 which dropped 29,000ft from 35,000ft over the North Atlantic on February 3, the *Daily* has learned. Exhaustive tests of the autopilot conducted both in the plane and on test benches failed to indicate that it was working improperly at the time of the incident. Early press reports had said that the fault was thought to be in the autopilot.

"Tests on the equipment were conducted by engineers at the Transport Division of Boeing Airplane Co., Renton, Wash, where the plane returned for inspection. Reportedly, tests were run by Boeing, Bendix, F.A.A. and C.A.B. specialists.

"The autopilot is a model PB-20D built by the Eclipse-Pioneer Division of Bendix Aviation Corporation. It is described as a type which uses a 'comparator' to sense deviations from normal flights. When the plane's course or attitude reaches tolerance limits of the equipment a light comes on and a horn blows and the autopilot automatically disengages. The pilot would then take over, correct the deviations and then return to autopilot."

With regard to the second happening, when the 707 aircraft lost an engine, an extract from *Aviation Week* is relevant:—

"Company spokesmen say Capt. Ryan was demonstrating minimum control speeds at 8,000ft under the airline's prescribed training programme when the 707 stalled at an estimated speed of 120 kt and started into a right spin. The plane lost 2,000ft of altitude and the violence of the recovery maneuver tore the engine and pod mounting from the wing."

Although Pan American have not issued an official statement in respect of either event, I suggest that there is sufficient evidence in both cases to absolve the autopilot from blame.

The Bendix PB-20 autopilot has completed many thousands of

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hours of scheduled airline flying, being fitted to aircraft operated by Air France, Lufthansa and Pan American. It is the most advanced autopilot in the world today and is held in high regard by pilots who use it regularly. Our latest information indicates that it has already reached a high standard of component reliability. Its excellent performance and high standard of reliability were the dominating factors in its selection by Vickers-Armstrongs Ltd. as standard equipment for their VC.10 aircraft.

London, W.1. E. G. MONK,
Managing Director, Bendix Ltd.

[A full C.A.B. report into the dive, which the Board classifies as an accident rather than as an incident, may be available next month—Ed.]

RECENTLY, as has been reported already in your columns, a Boeing 707 dived a considerable distance, causing its occupants great distress; from another, an engine fell out—an unprecedented occurrence in peacetime, though I am open to correction.

If this had been a British aeroplane it would probably have been taken out of service and extensive tests undertaken. Surely reflecting the confidence in which the Americans hold their aircraft is the fact that there was no talk, on their side of the Atlantic at least, of its being taken out of service. It makes one think just how far our industry has to go to reach that level of confidence.

Wembley, Middx. HARALD GINSBERG.

Clothing the Student Body

IN the issue of *Flight* dated March 6, comment was made ("Straight and Level") on the dress of several R.A.E. apprentices at the recent prizegiving ceremony. It was stated that the people concerned were dressed in a manner more suited to stripping a motor cycle than to receiving a prize. May I point out, Sir, that until half-an-hour before prizegiving, the apprentices concerned were quite probably working on an aircraft or in a machine shop or laboratory. Under these circumstances it is difficult to retain the clean, well-pressed appearance which your contributor seems to think is a necessity for a good engineer.

The R.A.E. apprenticeship scheme does not produce models of sartorial elegance, but it does give a training second to none, and produces craftsmen, technologists and engineers comparable with those produced by any other organization in the country. Surely an apprentice should be judged by his technical ability rather than by the creases in his trousers?

Farnborough, Hants. J. T. SHEPHERD.

[Roger Bacon writes: "Quite *probably* working on an aircraft, Mr. Shepherd? Well, *were* they? And suppose they were: would not thirty minutes be long enough for a spruce-up? As for the merits of the R.A.E. apprenticeship scheme, did you *read* the first paragraph of my comment?"]

Airfield Nostalgia

I READ with interest A. M. Pennie's article, "Assiniboia Revisited" [*Flight*, January 30]. I am sure that the nostalgia experienced by the author has been felt by many Air Force personnel who served in different parts of the world.

I was stationed in England with the 56th Fighter Squadron, U.S.A.A.F., from January 1943 until June 1945. During that period we were located at Kings Cliffe, Horsham St. Faith, Halesworth and Boxsted. Considering that sixteen years have elapsed since visiting these places, it is natural that my memories are becoming dimmed.

I am sure that a pictorial and historical sketch of British air bases would interest *Flight* readers of all countries.

New York. URBAN J. SWEENEY.
(Reference Librarian, Republic Aviation Corporation).

Speed and the Airline Passenger

THE many pages of entertaining photographs in your recent anniversary issue were most appreciated. I am afraid the majority of American editors and publicists take themselves and their subjects so damned seriously that they have lost the human quality of being able to enjoy things!

This remark in turn leads me to say something about Mr. J. R. Howard's comments (Correspondence, January 2) on the attractions of low-speed, low-altitude passenger flights. That issue reached me just a few days before the Electra crash at La Guardia, New York, and "prepared" me for that sad news. I have a premonition that before the year is out one or another of the transatlantic jets is going to be involved in some terrible mishap and I, for one, am quite unhappy about the current emphasis on speed. I agree with Mr. Howard completely. I make two or three business trips each year by airline and, although I have been a sport flyer since 1935, I must say I do not particularly relish airline travel. When I have to go somewhere I consider the "accidents-per-jillion-mile" statistics and, thus emboldened, make my reservation. Yet I do feel better when the trip is over. I cannot shake loose from the haunting spectre presented by the fact that when one of these high-speed machines does get into trouble there's precious little chance of those aboard surviving. It just simply weighs too much and hits too hard. And now we are rushing into faster, heavier jets.

Our long-distance railroad and bus lines are not reticent about advertising the scenic opportunities of their modes of travel. We have "Vista-Dome" railroad cars and "scenic routes." I sometimes wonder if some of the current popularity of light executive transports may not be due more to a yearning to "get away from it all" by making long, fascinating sightseeing flights, than to a terrible urge to save a few hours.

Does not the current surplus of piston-driven transports suggest possibilities for experimenting with sightseeing flights? I am no engineer, but I assume they could be modified for very economical, low-level operation. And, too, we must encourage some airline to experiment in the off-season with sight-seeing trips in the new Fokker Friendship. Our world is so beautiful from the air that such trips can inspire us to keep trying in our efforts to overcome the miserable problems which beset us on its surface.

Osterville, Mass. ROBERT J. WHITTIER.

Starter/Generators

I FEEL that, having regard to my comments on aircraft electrical systems in your issue of May 2, 1958, I am one of those at whom Roger Bacon ["Straight and Level," February 27] is tilting in his reference to starter/generators on the Russian An-10 aircraft. In the words of the popular television quiz games, "I accept the challenge."

The reasons for attempting to produce a starter/generator as a combined unit for aircraft are (a) to economize in space and the number of drives on/from the engine shaft, and (b) to reduce the weight of the starter and generator combination. It is by no means impossible to design a starter/generator which will give the required output as a generator and torque as a starter. The problem is to do so within a frame size that can be accommodated within the engine nacelle and at a sufficient saving in weight over the two separate machines not to be exceeded by the additional control gear and wiring. Moreover, a starter is usually designed to a low-gear-ratio drive to give the best torque and acceleration at low engine-shaft speeds. Unless it is thrown out of gear as the engine starts up, at full engine speed the centrifugal forces on the armature would be perilously close to bursting magnitude. These are the factors which govern the compromise since, for a given frame size, the optimum performance as a generator and as a motor cannot be achieved simultaneously.

One thing Roger Bacon apparently missed. The article referred to *two* starter/generators per engine; that is, eight in all. There is, therefore, little reason to assume that there is any saving in space or weight over the separate starter and generator combination, but there must be some complication in the circuits. Now my chief quarrel with the aircraft industry is that it constantly complains about the increasing complexity of electrical circuits but does nothing about it. Rather it chooses, for a variety of reasons—few of which are valid—systems which are even more complex. Apparently the Russians are no exception.

I gave an illustration of the complexity of a starter/generator circuit in my article, and while this could be simplified (and probably has been, by the Russians), there are certain components which cannot be omitted. The maintenance engineer faced with the broad specification of the An-10 might well remark "Eight starter generators, eight contactors, eight overspeed relays, eight voltage regulators, eight differential relays, eight reverse current circuit breakers, eight field relays, eight no-volt relays, eight equalizing circuits and contactors and eight of everything else all on one machine.. . . . Ooo, 'ell!!!

Thames Ditton, Surrey. LIONEL G. HILL.

FORTHCOMING EVENTS

Mar. 25. R.Ae.S. Graduates' and Students' Section: "Aircraft Escape Techniques," by J. Martin.
Mar. 25. British Institution of Radio Engineers; Symposium on Radio Telemetry.
Mar. 25. Kronfeld Club: "Soaring and Cross Country Flying," by Tony Goodhart.
Mar. 27-30. Easter Gliding Rally, Long Mynd.
April 1. Kronfeld Club: "Field Landings and Retrieving," by Lorne Welch.
April 3-5. Aslib Aeronautical Group: Annual Conference.
April 4. Helicopter Association (Regional Lecture at Southampton): "Effect of Size of the Helicopter on its Economics," by Raoul Hafner.

June 12-21. Paris Aero Show.
Sept. 7-13. S.B.A.C. Display and Exhibition, Farnborough.

R.Ae.S. Branch Fixtures (to Mar. 27): Mar. 24, *Luton*, a.g.m. Mar. 25, *Bristol*, a.g.m. and film show; *Glasgow*, "New Supersonic Wind Tunnel," by A. C. Smith; *Preston*, "The Application of the Area Rule to Aircraft Design," by W. T. Lord; *Reading*, a.g.m. and film show; *Southampton*, a.g.m.; *Weybridge* (joint meeting with the Institution of Mechanical Engineers), "Guidance and Control of Missiles," by L. H. Bedford.

THE INDUSTRY

Identification by Etching

EQUIPMENT for marking metal parts by etching with the American Lectroetch process is now being manufactured in this country by the Neil Tool Co. Ltd., who hold sales rights for Europe and the British Commonwealth with the exception of Canada.

Etching was employed by the American company in 1943 for marking engine parts whose strength might be seriously affected by conventional impact marking methods. Lectroetch is now being used by Boeing, Lockheed and many other aircraft and automobile manufacturers as well as in several other industries. It is particularly suited for marking highly stressed components such as turbine blades. Applying the reverse of the electroplating process, current from a rectifier unit is passed through the work-piece and into a hand-held contact incorporating a pad for the etching fluid and a special plastic stencil. Either handwriting, typewriting or photographically reproduced images may be applied. The first two can be directly prepared on the spot, but the photographic process is at the moment available only from America.

Either white or black etching can be produced by switching for D.C. or A.C. current and a wide choice of fluids is available for marking almost any metal, including stainless steel, aluminium, tungsten carbide or brass. The etching pad, supplied in various sizes, is housed in a plastic holder containing a reservoir for fluid and can be used to mark flat or curved surfaces and tubes down to ¼in diameter. The holder can be taken apart without tools and a new stencil applied in seconds. It is stated that a typed stencil will last for several hundred applications, that the depth of etch does not exceed 0.003in, and that the fluids used are non-toxic and have no continuing action after application. The Neil Tool Co. is located at Bysouth Works, Dorset Road, London, N.15.

An American turbine blade bearing an etched marking produced from a typewritten stencil. The equipment used is described here

Seeking the Right Material

AS part of a programme for expanding their scope, Materials Data Ltd. (see *Flight*, March 14 and December 19, 1958) have set up—at 273 Farnborough Road, Farnborough, Hants—a materials information centre for the aircraft industry. Up-to-date information on a number of new materials has not previously been readily available and the centre aims to present information promptly and comprehensively, giving such essential commercial details as sources and costs. As part of the facility it will be possible to select the best material for any particular application by a comparison of technical possibilities, and as a permanent establishment the centre will be able to provide a better reference on comparative materials than by marshalling reports and technical literature.

Reaction to the company's idea has already been favourable and the English Electric Company and the Atomic Energy Authority are included among subscribers.

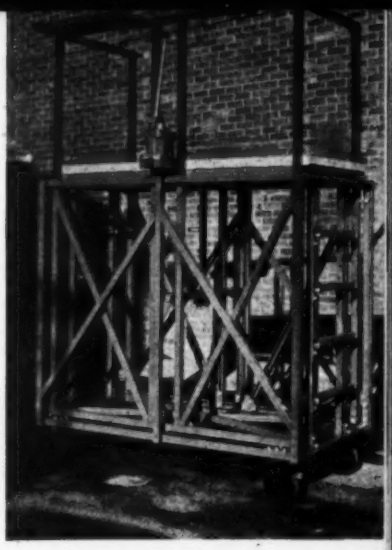
The method of operation is to open a file, arranged in ordinary alphabetical order, on individual grades of material; and there is an associated service—of a kind believed not to have been attempted before—to correlate information on materials for purposes of comparison and selection of a desired combination of properties. This is done by calculating the ratios of density to strength, density to thermal conductivity, and cost to electrical resistivity; the materials are then arranged in corresponding order. The resulting lists show the suitability of any given material in a particular application and the materials list indicates savings that can be achieved in terms of volume, weight or cost, or by replacing one material by another. If, for example, a material should be required which has a high ratio of bending strength to weight at 800 deg C, high thermal conductivity and a high electrical resistivity, the appropriate 800 deg C list will show how well any material measures up to these factors ($w/f\frac{1}{2}$, k, c_p, R in the centre's scheme).

It is also possible to see what penalties would be involved in using other materials. The lists are constantly being revised and when the true "best materials" are included they should be particularly valuable. They should also serve to keep users in constant touch with developments in the materials world.

Typical numerical results obtained from these lists show that a magnesium-alloy rod will weigh about 36 per cent less than a silver rod which conducts the same amount of heat, and that a beryllium wire will conduct as much electricity as a copper wire for half the weight. These results were obtained by an electronic computer using punched-card techniques. About 40 property ratios were calculated and the computing time for 100 materials yielding 4,000 results was approximately 17 sec. Naturally, it took much longer to deal with the data before and after the computing stage.

In principle, the centre gives general access to the information that is obtained, while distinguishing between information for which there is a wide demand and that which is required for the purposes of private technical assessment. It is possible, the directors say, that some higher ruling will emerge and that membership may become restricted to British organizations and individuals.

[contd. overleaf



This hydraulically operated aircraft maintenance stand, developed for F.A.A. use in servicing Scimitars, has been constructed from the Unistrut steel channel framing system by the Unistrut division of Sankey-Sheldon Ltd., 43/45 Broadwater Road, Welwyn Garden City, Herts. Its load capacity is half a ton; the working platform rises from 2ft to just over 8ft in approximately 65 sec, actuated by a hand-operated hydraulic jack, for which Power Jacks Ltd., Valetta Road, Acton, London, W.3, are responsible

Illustrated on the left is the "File-a-Plan" cabinet for storing some 600 blueprints, tracings, charts and similar documents. The drawings are suspended from sliding holders, so avoiding creasing, and the front panel contains an index. Both horizontal and vertical types are available from the makers, who are Renown Metal Works Ltd., Sulivan Road, London, S.W.6

Mr. Charles Boon, inspector-in-charge at the Hurn depot of Vickers-Armstrongs (Aircraft) Ltd., recently retired after 44 years. In 1919 he was detail inspector on the construction of the transatlantic Vimy. His retirement was marked by a presentation from Mr. D. Gammon (left), deputy managing director

THE INDUSTRY . . .

It is visualized that the centre will work in the manner of the Stock Exchange. Additions and modifications to the information will be added with minimum reference to the centre; it may, for example, be beneficial for materials manufacturers to have their products correctly and adequately represented on the centre's lists for automatic distribution to members.

Not every manufacturer is mentioned in the preliminary lists, which are intended to illustrate proposed work. But it is felt that the onus of ensuring correct representation is as much on the manufacturer as on the centre. It might be asked if, when this comes about and every grade of every known material is listed, the centre will not become impracticably large. But thanks to the use of punched-card techniques all the information can be stored on up to 10,000,000 cards in a room measuring about 20ft × 10ft × 10ft. The centre ensures that the information on each grade of materials passes through some routine processing leading to fair representation on the data cards and in the comparative lists. The directors say that worthwhile modifications can easily be incorporated at this early stage and that they are very ready to consider comment and criticism of their plans.

Confidence in Cameras

WELL known as old-established makers of air cameras and other photogrammetric equipment, the Williamson Manufacturing Co. Ltd. held their annual dinner in London on March 6. In the chair, in person, was Mr. Colin M. Williamson (chairman and managing director), who was able to claim that his voice had been heard at every annual gathering of the company—another way of saying that when a trip abroad has conflicted with the event a tape recording of his speech has been played back to the assembled company. He laid stress on the long service of many members of the firm: 44 had served for 20 years or more and 17 of the higher executives had put in 553 years between them.

The advent of radar reconnaissance is, of course, having some impact on the firm's business and Mr. Williamson recalled reading a paper over 30 years ago in which he predicted the probability of some such development.

Mr. John Odle (joint managing director), who is now responsible for the day-to-day conduct of the business, forecast a big future for the company's products, radar reconnaissance notwithstanding. Coastal Command, he said, would have the electrically operated, hand-held, Type 117 camera and the company had obtained a large order from the United States for processing plant.

IN BRIEF

The R. B. Pullin group of companies announce that their net consolidated trading profit (after tax) for the year to September 30, 1958, has at £149,458 "more than doubled."

* * *

Mr. Eric K. Cole, C.B.E., chairman and managing director of E. K. Cole Ltd., has been elected an honorary member of the British Institution of Radio Engineers in recognition of his services to the radio and electronics industry and profession.

* * *

Mr. J. D. Sinclair, formerly with Muirhead & Co. Ltd. as assistant chief of sales, has been appointed manager of the Industrial Division of Amplivox Ltd. He will be concerned with marketing electro-acoustic equipment in the aeronautical and industrial communications field.

Mr. W. H. Haydon-Soutar, A.M.I.Mech.E., A.F.R.Ae.S., has been appointed chief engineer of Aero Controls Ltd., Northampton. Associated with the aircraft industry for over 20 years since an apprenticeship with Hawker Aircraft, he has held increasingly responsible appointments with Hunting, Flight Refuelling, Edgar Percival, SPE and Brooklands Aviation. His appointment signifies a number of new developments in the products of Aero Controls

A semiconductor application report on *D.C. Power Supply Circuits Using Silicon Rectifiers* (the fourth in a series) has been published by Texas Instruments Ltd., Dallas Road, Bedford. Its aim is to draw attention to the particular design features of circuits using silicon rectifiers. Worked examples are given and both drawings and graphs used as illustrations.

* * *

The Instrument Division recently announced by Racal Engineering Ltd. has been formed into a new company known as Racal Instruments Ltd. in order to give greater scope for production and development of current and forthcoming instruments. Mr. J. H. Head, formerly with Advance Components Ltd., has joined the new company as director and general manager.

* * *

The Savage and Parsons memorial prizes (for mechanical engineering and electrical engineering respectively) awarded annually to outstanding students of Watford Technical College have been won this year by Edward Conrad Koeppl (21), an apprentice at the de Havilland Engine Co. Ltd., and Philip David Garment (19), who is with the D.H. Aircraft Co. Ltd.

* * *

Brush Crystal Co. Ltd., of Hythe, Southampton, announce that they have started commercial production of new piezoelectric materials. Polycrystalline ceramics based on a lead zirconate-titanate solid solution, they are stated to possess high conversion-efficiency combined with a usable temperature range of up to 250 deg C. Applications include pick-up elements, accelerometer and pressure cartridges, flaw-detection probes and high-power ultrasonic transducers.

Simmonds Aerocessories Ltd. announce the formation of Simmonds Aerocessories (Belgium) S.A. as a subsidiary company. Offices are at 25 rue Faider, Brussels, the manager is Mr. George Harms, and the company will handle Simmonds self-locking nuts, Spire Speed nuts, and the products of Firth Cleveland Instruments Ltd.

Mr. Laurence Malec, M.B.E., A.R.Ae.S., who has joined Solartron Electronic Group Ltd. as managing director of Solatron Radar Simulators Ltd. He was commissioned in the R.A.F.O. as a pilot in 1934 and during the war held various R.A.F. posts, several concerned with instrument flying. On demobilization he joined B.E.A. and was in charge of all synthetic-training equipment; in 1948 he went to Air Trainers Link whose managing director he became in 1953

Mr. Peter Alsop has left E.M.I. Electronics Ltd., where for the past three years he has been employed in an advisory capacity on the application of new techniques and processes, including printed circuitry and resin encapsulating. He has joined Technograph Electronic Products Ltd., where he is responsible for the Technical Sales Division in the computer, guided weapons and airborne equipment fields.

* * *

A large extension has been opened to the Castrol laboratories at Hayes, Middx. Equipment in the spectrographic laboratory includes apparatus for analysis of the metallic constituents of oil samples; in the radio-chemical laboratory, research is conducted with the aid of isotopes; and in addition to such new facilities, considerable attention has been paid to the provision of equipment and services for more routine laboratory work.

A former graduate apprentice of the English Electric Co. Ltd., Mr. J. F. W. Bowshill, B.Sc.(Eng.), has been appointed Napier resident technical representative for South, Central and East Africa. He succeeds Mr. P. S. Dedry. Mr. Bowshill has spent most of his life in South Africa, but came to England for his apprenticeship in 1955. For the past 18 months he has been with Napier's Turbo-blower and Deltic (high-speed diesel) sales departments

The Marconi AD.722 sub-miniature automatic radio compass, which weighs only 22 lb complete, is being increasingly used in helicopters. Recent installations have been in the Bristol 192, Westland Whirlwind, Agusta-Bell 47G and Sud Aviation Alouette, and now an order has been received for AD.722s to be installed in two Westland Widgeons for Bristow Helicopters Ltd. The design uses a fixed crossed-loop aerial of the Bellini-Tosi type. The loops are moulded in plastic to provide a unit only ½in deep, which in helicopters is mounted in the lower fuselage.

[redacted]